TM 5-475

WAR DEPARTMENT TECHNICAL MANUAL

U.S. Dept. of Army

MILITARY DIVING

WAR DEPARTMENT • 1 SEPTEMBER 1944

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This manual supersedes TM 5-475, Diving Manual, 25 September 1943.

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For explanation of symbols, see FM 21–6.

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CONTENTS

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SECTION I

PHYSICAL AND MENTAL QUALIFICATIONS

1. GENERAL. Before a man can become a diver he must have certain physical and mental qualifications. A diver is alone under the water; against the dangers he may meet he has only his diver's dress, his technical knowledge, and his common sense to help him. In addition to knowing how to protect himself against pressure, falls, and fouling, a diver must be a skilled workman, for he must assist in repairing sunken ships, salvaging cargoes and machinery, restoring harbor facilities, clearing underwater obstacles, and saving the lives of those trapped under water.

2. QUALIFICATIONS. a. General. (1) The qualifications for a diving candidate are given in detail in AR775–50, C 4, 40–100, and 35–1485. These regulations should be read thoroughly. They are the diver's guide throughout his Army diving career. From them the diver learns that he must keep himself physically fit and mentally alert if he is to succeed.

(2) The few simple rules and safety precautions that are found in the proper sections throughout this manual and are *italicized* for emphasis should be studied. A diver who becomes overconfident and disregards these rules will eventually suffer serious consequences—even death.

b. Mental ability. Diving often requires quick, accurate judgment, and initiative. Minimum scores of 90 in the Army General Classification Test and 90 in the Mechanical Aptitude Test are required. Experience has shown that high mental ability is necessary to work properly under increased air pressure.

c. Temperament and habits. Since excitement and fright are accompanied by a quickening of the pulse and a rise in blood pressure, a diver should be calm and quiet. The rate of saturation and desaturation of the body tissues is influenced directly by the rate of blood flow and a calm diver is less likely to develop compressed air illness than an easily excited diver. A diver's habits must be moderate because drinking, loss of sleep, or dissipation increases susceptibility to compressed air illness.

d. Age. Candidates for diving training should be under 30 years of age. When a diver, first class, reaches 40 years of age or becomes unfit to dive in depths over 90 feet, he is automatically disqualified but may continue as a diver, second class, as long as he is physically fit for diving to restricted depths. Because the respiratory exchange is faster in young men than in men of middle age, young men can rid their bodies of excess nitrogen more rapidly and so are less susceptible to compressed air illness, commonly known as the "bends." The heart and blood vessels are other important factors in diving; here again the younger man is better suited for the work; with the approach of middle age, the body tends to accumulate more fat which is a detriment.

e. Weight. Fatty tissue has a relatively poor blood supply and absorbs and eliminates nitrogen more slowly than other tissues. Therefore, men who are overweight are more likely to suffer from compressed air illness.

f. Vision. Despite the use of diving lamps, underwater illumination is

usually poor. Since it is impracticable to wear glasses in a diving helmet, good vision is essential. For master divers and divers first class, a minimum of 20/20 vision in each eye and normal color perception is required. For salvage divers and divers second class, a minimum binocular vision of not less than 20/40 without lenses is required and defective color perception is not disqualifying.

g. Lungs. Candidates must be able to hold their breath after full expiration and inspiration for at least 55 seconds. This is based on the average results of three tests. The lungs act as a station for the exchange of gases between the atmosphere and blood stream. To perform this task well they must be free from disease. Further, since high atmospheric pressures irritate the lungs, evidence of pulmonary disease disqualifies a prospective diver.

h. Heart and blood vessels. Diving candidates must take a circulatory efficiency test. How this test is given and graded is found in C 4, AR 40–100, 22 July 1943.

i. Digestive tract. Men with digestive disturbances and a tendency to form excess gas in the stomach and intestines are not accepted. The marked expansion of such gas on ascending from even moderate depths may induce severe symptoms if not expelled readily. For the same reason, when a diver is constipated he should not be allowed to dive.

j. Disqualifying diseases. (1) One of the most important of the disqualifying diseases is middle ear disease, which not only diminishes hearing but usually blocks the Eustachian tube. The Eustachian tube extends from the middle ear into the throat. When air under pressure enters the external ear it tends to push in the flexible ear drum. At the same time, however, air enters the nose and mouth and flows through the inner end of the Eustachian tube to the inner surface of the drum, where it equalizes the pressure coming through the external ear. Consequently, if the Eustachian tube is blocked, the pressure on the outside of the drum continues until the drum ruptures. Mucus or local inflammation caused by a cold or sore throat frequently blocks the tube temporarily. Mucus usually can be expelled and comfort obtained by yawning or swallowing. However, if inflammation is present, forced expiration with obstruction of the nose and lips closed may force infected matter through the tube into the middle ear and infect it. *Exposure to increased air pressure should not be undertaken if you have a cold or other local inflammatory condition of the upper respiratory tract.* In addition to colds, chronic disorders of the upper respiratory tract like tonsilitis, chronic sore throat, nasal obstructions, or sinusitis usually block the Eustachian tube and are cause for rejecting a diving candidate. The ability to equalize pressure in the ears is part of the physical examination and is determined by subjecting the candidate to 60 pounds of air pressure in a recompression chamber.

(2) Other disqualifying diseases are syphilis, asthma, persistent high pulse rate, and psychiatric or nervous diseases.

k. Reexamination before diving. Divers are examined periodically to detect disqualifying defects that may have developed since the last examination. A special examination is made before any diving operation in water over 36 feet deep. The results of the examination are recorded and the medical officer decides whether the diver is physically fit to dive on that particular day. A temporary physical defect does not disqualify the man as a diver but may excuse him from being ordered to dive at that particular time. At this time a short history of the diver's activity during the preceding 24 hours is also obtained. The following facts are stressed:

(1) *Amount of sleep.* Less than 8 hours sleep the night previous to diving makes the diver more susceptible to compressed air illness.

(2) *Alcohol.* Divers are not allowed to dive if alcohol has been consumed in the past 24 hours.

(3) *Constipation.* Lack of bowel movement in 24 hours increases susceptibility to compressed air illness.

(4) *Symptoms of colds or sore throat.* A cold or sore throat may block the Eustachian tube and cause rupture of the ear drum when subjected to air pressure.

3. OUTLINE OF TRAINING PROGRAM. a. General. Diving candidates who meet the required mental and physical standards take the 12-week course in diving and salvage operations.

b. Standard course. The curriculum of the standard 12-week course includes the following:

(1) Diving team problems in timber, steel, and concrete construction, demolition of docks, piers, and ships, and actual salvage operations.

(2) Individual diving problems in reconnaissance, pipefitting, patching, and survey of underwater conditions in mud, swift currents, and various tides, and use of jetting nozzle and siphon.

(3) Use of hand tools, air tools, machine tools, pumps, winches, and blacksmith equipment.

(4) Rigging, beach gear, and hi-lines.

(5) Underwater oxyelectric welding, burning, and cutting, and underwater oxyhydrogen and electric cutting.

(6) Elementary instruction and training in—

(*a*) Diving-gear nomenclature.

(*b*) Diving-gear maintenance.

(*c*) Hazards of diving.

(*d*) Physics of diving.

(*e*) Skin diving.

(*f*) Recompression tanks and tables.

(*g*) Air compressors, air flasks, and field expedients.

(*h*) Signals and communications.

(*i*) Ship construction.

(*j*) Mooring and maneuvering.

(*k*) Sketching.

(*l*) Tactical military instruction.

SECTION II

PHYSICS OF DIVING

4. GENERAL. We now consider air and water, the elements with which divers work.

5. LAWS OF PHYSICS. a. Boyle's law. Boyle's law states that at a constant temperature the volume of a gas varies inversely as the pressure; the density varies directly as the pressure. In other words, increased pressure on a gas decreases its volume and increases its density in direct proportion to the pressure applied and vice versa. Thus, if the pressure is doubled, the volume is decreased to one-half; if tripled, the volume is decreased to one-third.

b. Charles' law. Charles' law states that at a constant pressure the volume of a gas varies directly as the temperature based on absolute zero. That is, as the temperature increases, the volume increases, and vice versa. On the Centigrade scale, the volume of a gas varies 1/273 of its volume at 0° C. for every variation of 1° C.; on the Fahrenheit scale, the volume of gas varies 1/491 of its volume at 0° F. for every variation of 1° F.

6. AIR. a. Physical characteristics. (1) The air we breathe is a single mixture of gases. The main components and their approximate proportions by volume are:

		Percent
Nitrogen	(N_2)	79.00
Oxygen	(O_2)	20.96
Carbon dioxide	(CO_2)	0.04

There are also traces of hydrogen and certain rare gases. When air is compressed, the proportions remain the same, in accordance with Boyle's and Charles' laws. However, the amount by weight of each component per cubic foot is increased.

(2) Air has weight and therefore exerts pressure. At sea level, atmospheric pressure is 14.7 pounds per square inch. This is called 1 *atmosphere* of pressure. To convert pressure in pounds per square inch to atmospheres, divide by 14.7. Thus, 44.1 pounds pressure per square inch equals 3 atmospheres. To change from atmospheres to pounds per square inch, multiply by 14.7.

b. Components. The three main components of air all play an important part in diving.

(1) *Oxygen.* Oxygen, a colorless, odorless, tasteless gas, is the part of air necessary to life. To sustain life air must contain a certain amount of oxygen. When air is compressed at high pressures, the amount of oxygen per cubic foot increases and the volume needed is less. Conversely when atmospheric pressure is low, the weight of oxygen per cubic foot decreases and the volume must be increased. At sea level the air must contain at least 13 percent oxygen to provide an adequate supply for a person at rest. When diving, the greater pressure below sea level compresses the air, there is more oxygen per cubic foot, and the percentage of oxygen required is smaller. When the body is active and needs more oxygen, it gets it by faster breathing. Lack of oxygen deadens the faculties, slows a man's reactions, and rapidly causes unconsciousness and death. Normally there are no warning symptoms.

(2) *Nitrogen.* Nitrogen is a colorless, odorless, and tasteless gas. Normally it has no effect on the human body, but for a diver it creates a serious problem. Under pressure, the nitrogen breathed into the body passes through the walls of the blood vessels and is dissolved in the blood and surrounding tissues. When pressure is decreased slowly, the nitrogen is released slowly from solution and passes out of the body. However, if the pressure drops suddenly, nitrogen bubbles remain in the body and cause "bends." (See par. 40b.)

(3) *Carbon dioxide.* Carbon dioxide is a colorless and odorless gas. A small amount of carbon dioxide is necessary as its presence regulates breathing. However too great concentrations are dangerous. At sea level, about 3 percent is the maximum that can be tolerated without distress. A concentration of 8 percent causes severe headaches, dizziness, and slowed reactions; 10 percent causes unconsciousness and death by suffocation. Carbon dioxide is formed inside the body by the chemical combination of carbon and oxygen and is passed out in the breath. In an enclosed space like a diver's helmet, dangerous concentrations of carbon dioxide can result if the exhaust regulating valve is not functioning properly.

7. WATER. a. General. The pressure of a 33-foot column of sea water is 14.7 pounds per square inch or 1 atmosphere. But there is also 1 atmosphere of pressure on the top of the water column caused by the weight of air above it. Therefore the absolute pressure at the bottom of the column is 2 atmospheres. For every foot of depth, sea water itself exerts a pressure of $14.7 \div 33 = 0.445$, or roughly one-half pound per square inch. Fresh water is slightly lighter and it takes a 34-foot column to exert a pressure of 1 atmosphere.

b. Pressure on submerged bodies. A submerged body is considered to be under a column of water which exerts pressure in proportion to its height. A body has less pressure on its top than on its bottom because of the difference in height of the water column. Thus a 6-foot diver has about 3 pounds less pressure on his helmet than on his shoes.

c. Buoyancy. A submerged body displaces a volume of water equal to its own volume and a pressure equal to the weight of the volume of water displaced pushed up against the body. In sea water, this upward pressure is 64 pounds per cubic foot; in fresh water it is 62.5 pounds. If the weight of the body per cubic foot is less than the upward pressure, it has positive buoyancy and floats. If it is more, it has negative buoyancy and sinks.

8. EFFECTS OF WATER PRESSURE ON DIVING. a. "Squeeze." A diver who falls any great distance under water is subject to the danger of "squeeze." The sudden increase in depth results in an equally sudden increase in water pressure which compresses the air into a smaller volume and forces it from the diving dress into the rigid helmet. If the volume of air is so decreased that it does not fill the helmet and if its pressure is less than that of the water, the diver's body is squeezed up into the helmet. Serious injury or death can result.

(1) Falls from shallow to deep water are more serious because the relative difference in pressure is greater. The pressure at the surface is 14.7 pounds per square inch. At 33 feet, the pressure is doubled and is 29.4 pounds per square inch. A fall of 66 feet triples the pressure and results in several tons increase in pressure.

(2) When the diver is initially in deep water and falls, the consequences are less serious, since there is only a small relative change in pressure. For example, a diver falls from a level of 165 feet to 198 feet. At 165 feet, pressure is 5 atmospheres and at 198 feet it is 6 atmospheres. Pressure is only one-sixth greater and the body is normally able to accommodate itself to this increase.

b. "Blowing up." Excess air overinflates the diving dress and may result in the diver being "blown up." When a diving dress is filled with air, the weight of displaced water is greater than that of the diver. Normally, weights are added in an amount enough to overcome positive buoyancy when the dress is moderately filled with air. If the suit is overinflated the weights do not hold the diver down. Once he starts rising, his speed accelerates rapidly. This is caused by the continued expansion of air in the dress as the depth and pressure of water decreases, making him more and more buoyant. A sudden rise and change of pressure can cause "bends." The diver can control the inflation of his dress by proper adjustment of his air-control and exhaust valves.

SECTION III

DIVING GEAR

9. GENERAL. A diver is dependent on his dress for protection. Consequently, he must know it thoroughly; its construction, how to get in and out of it, when it is in perfect order, when it needs adjusting, and how to adjust it.

10. DESCRIPTION AND NOMENCLATURE. a. General. The standard diving outfit includes the following items:

(1) The dress.
(2) Helmet and breastplate.
(3) Aircontrol and nonreturn valves.
(4) Regulating air-exhaust valve.
(5) Telephone and life lines.
(6) Jockstrap and weighted belt with knife attached.
(7) Shoes.

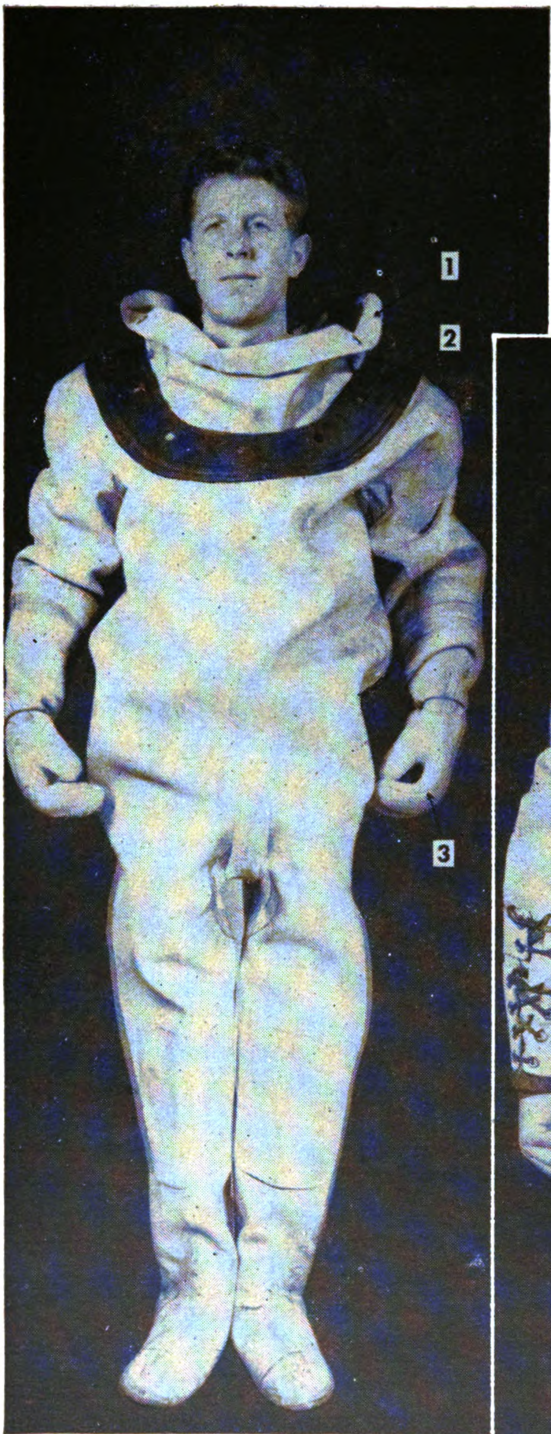
b. The dress. The dress itself is made of sheet India rubber backed with cotton fabric and reinforced at all points of wear. It has a rubber collar in which holes have been punched to receive the breastplate. Inside is a bib to trap water that may seep through the breastplate; this prevents leakage into the lower parts of the dress. The legs have lacing flaps to decrease the volume of air inside the suit. This prevents the legs from blowing up with air and thus destroying the diver's negative buoyancy. For cold water work, gloves are cemented on the sleeves.

c. The helmet. (1) The spun-copper helmet has four sight plates, the faceplate in front, one above it near the top, and one on the left and right sides, to give the diver maximum vision. The lenses of these sight plates are protected by metal guards. Only the faceplate in front is movable. The faceplate is sealed with a built-in rubber gasket. It swings on hinge pins and is locked by a wing nut.

(2) A locking device in the back of the helmet assures absolute safety. When the helmet is screwed into its proper position, a safety pin drops into a slot to prevent the helmet being accidently unscrewed.

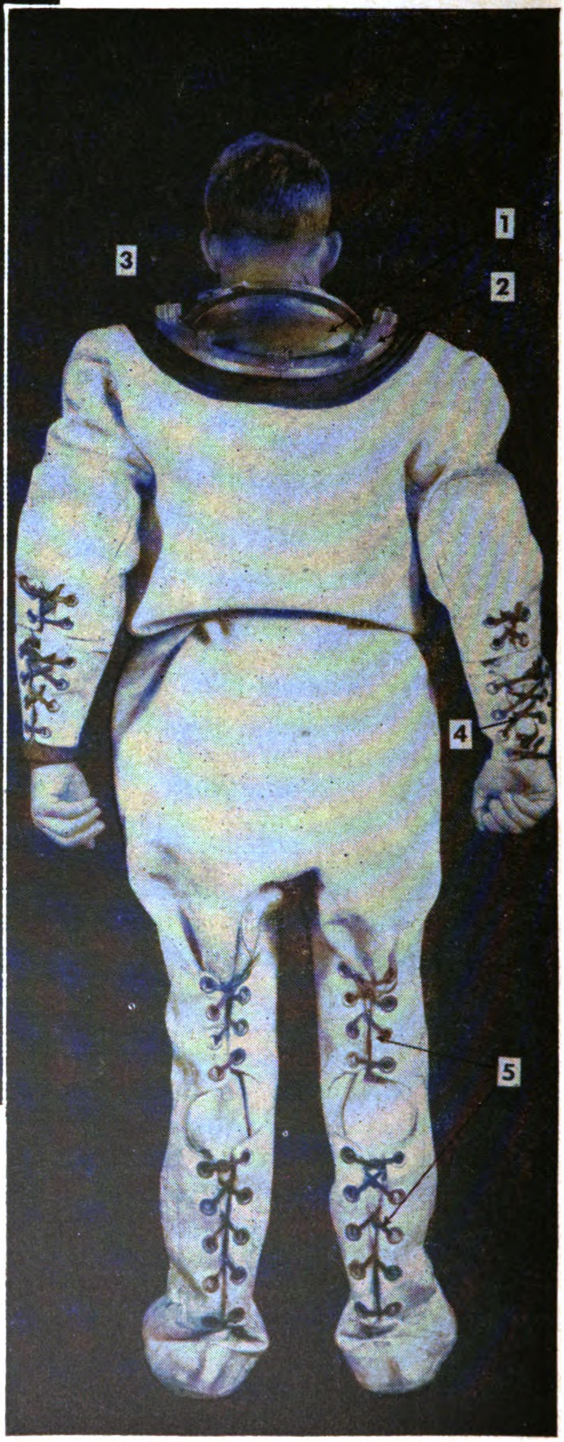
(3) Also in the rear of the helmet are gooseneck pipe fittings to which air and life lines are connected. The combination life line and telephone connection is on the diver's left. The air-inlet valve to which the air lines are screwed is on his right. This valve is of the nonreturn type. (See fig. 8.) It consists of a spring valve which seats against a leather washer. Air going through the air line overcomes the spring tension, opens the valve, and enters the helmet. If the air pressure decreases no air can come back into the air line because the valve closes. Normally about ¼ pound pressure per square inch will close the valve. Thus if his air line is severed or damaged, the diver is not squeezed by water pressure, since the pressure within the helmet is retained, and no air escapes.

(4) In front of the helmet on the right side is a nonblow type air-exhaust valve that regulates the flow of exhaust air and permits the diver to regulate the inflation of his dress and consequently his buoyancy. As the diver enters the water, his dress is subjected to an external pressure that forces the air in the dress up into the helmet and out the exhaust valve. If the escape of this



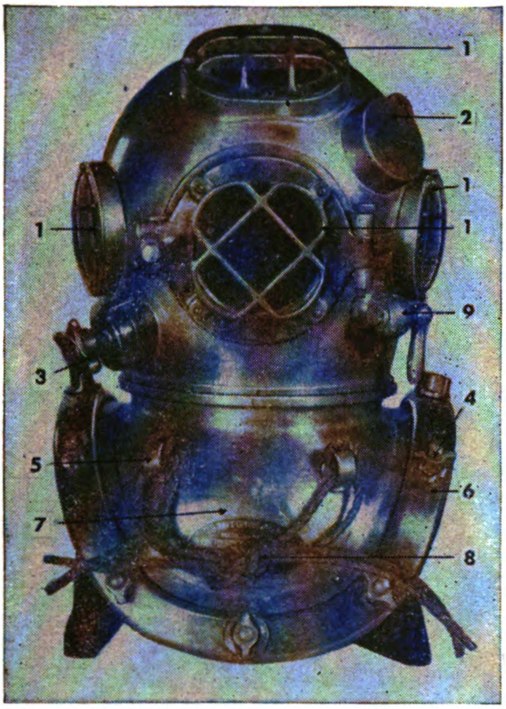
1. *Bib to trap seepage water.*
2. *Rubber collar.*
3. *Gloves cemented on the sleeves.*

Figure 1. Standard diving dress—front view.



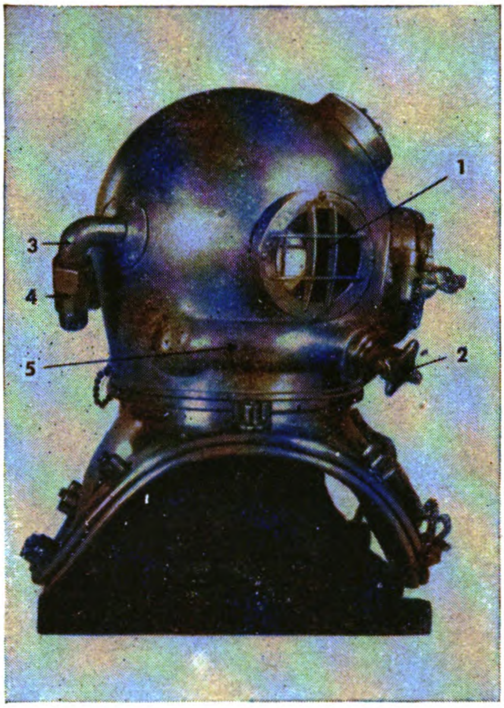
1. *Breastplate.*
2. *Breastplate clamps.*
3. *Wing nuts.*
4. *Sleeve lacing flaps.*
5. *Leg lacing flaps.*

Figure 2. Standard diving dress—rear view.



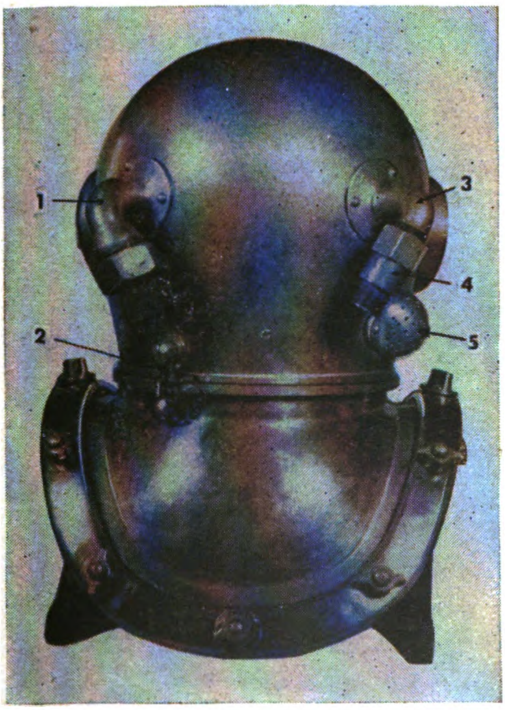
1. Sightplates.
2. Telephone recess
3. Regulating exhaust valve.
4. Wing nuts.
5. Pad eye.
6. Breastplate clamp.
7. Breastplate.
8. Lanyards.
9. Spit cock.

Figure 3. Standard diving helmet—front view.



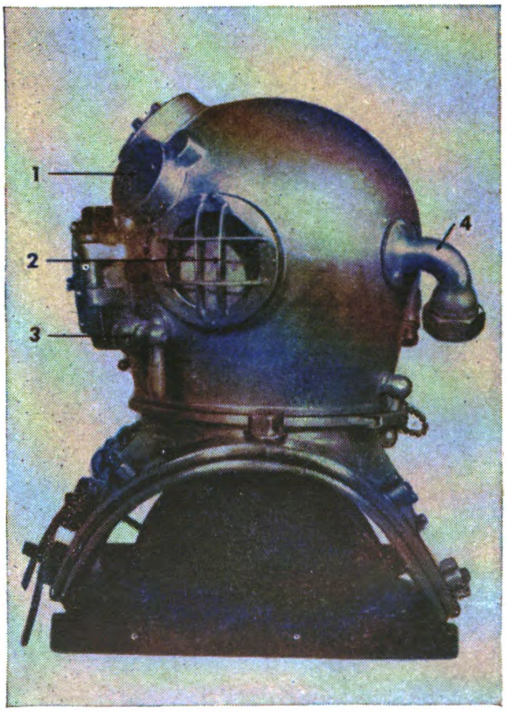
1. Sightplate.
2. Regulating exhaust valve handwheel.
3. Gooseneck, air hose.
4. Valve, safety, nonreturn.
5. Regulating exhaust valve body.

Figure 4. Standard diving helmet—right side view.



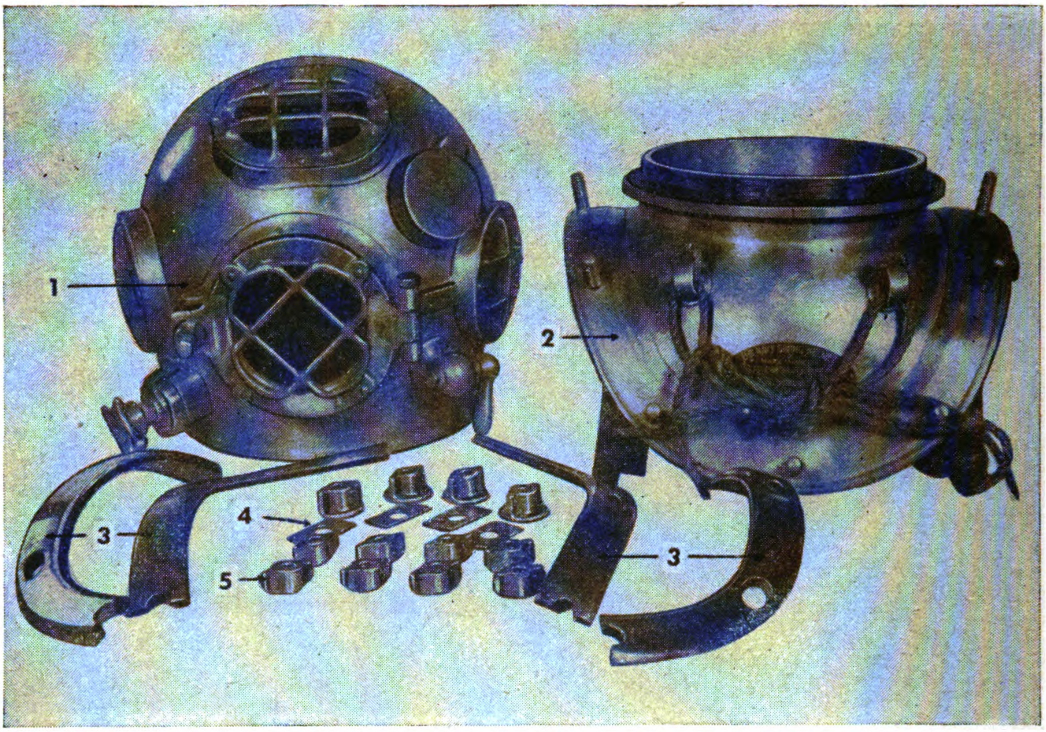
1. Gooseneck, telephone.
2. Lever, safety catch.
3. Gooseneck, air hose.
4. Valve, safety, nonreturn.
5. Regulating exhaust valve outlet.

Figure 5. Standard diving helmet—rear view.



1. Telephone recess.
2. Sightplate.
3. Spit cock.
4. Gooseneck, telephone.

Figure 6. Standard diving helmet—left side view.



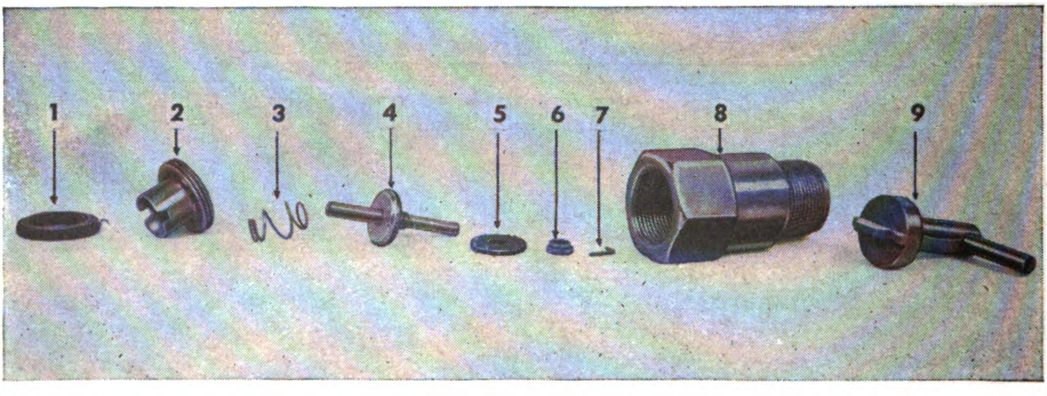
1. *Body washer.*
2. *Breastplate.*
3. *Breastplate clamps.*
4. *Shims.*
5. *Wing nuts.*

Figure 7. Standard diving helmet showing breastplate, breastplate clamps, washer, and wing nuts.

air is not retarded, the dress collapses and the diver cannot breathe. On the other hand, if the air cannot flow properly from the helmet, the diver's dress becomes overinflated and the diver may be blown to the surface.

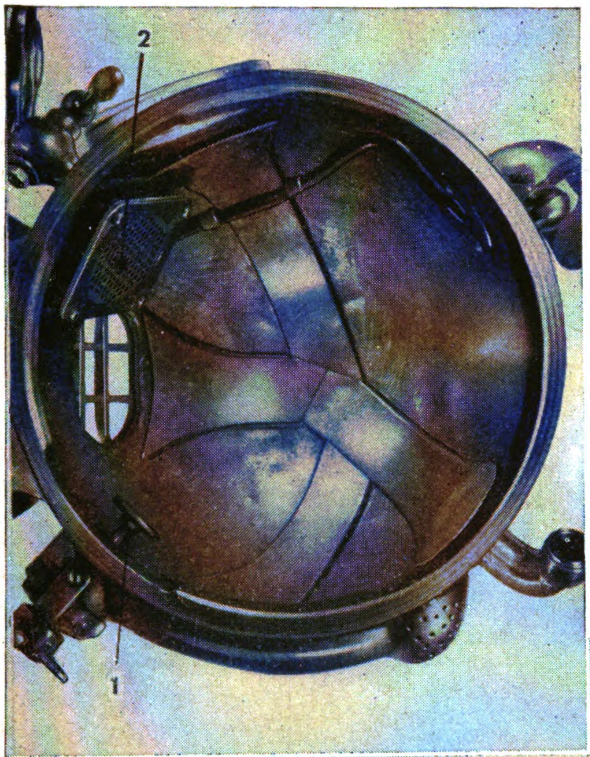
(5) The air exhaust valve is adjusted either by turning the outside handwheel (see (2), fig. 4) or by pressing the chin button on the inside of the helmet. (See fig. 9.) If the diver wishes to increase his buoyancy he partially closes the valve by turning the handwheel. If he desires to decrease his buoyancy, he partially opens the handwheel or depresses the chin button.

(6) The internal pressure in the diver's dress normally is about ½-pound per square inch greater than the external water pressure. The air exhaust valve has a primary valve spring that regardless of the setting of the handwheel closes the valve against the pressure. There is also a secondary valve spring that can stand a 2-pound pressure. When the regulating handwheel



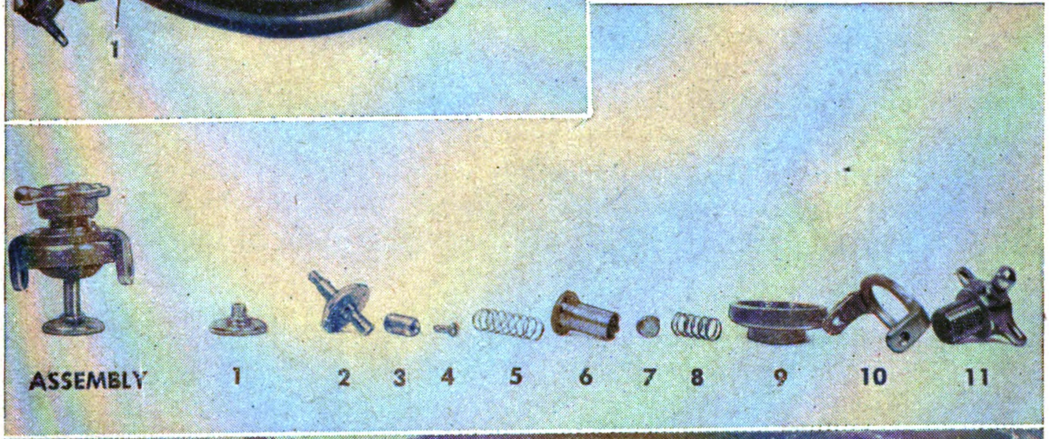
1. *Boy washer.*
2. *Upper guide.*
3. *Spring.*
4. *Valve stem.*
5. *Stem washer.*
6. *Stem nut.*
7. *Locking key.*
8. *Valve body.*
9. *Valve wheel.*

Figure 8. Valve, safety, nonreturn, disassembled.



1. Chin button.
2. Diver's Transmitter-reproducer unit installed in helmet.

Figure 9. Chin button inside helmet.



1. Chin button.
2. Valve stem.
3. Valve-stem adjusting sleeve.
4. Setscrew.
5. Primary valve spring.
6. Secondary valve cylnder.
7. Follower disk.
8. Secondary valve spring.
9. Valve-cap collar.
10. Valve-head collar.
11. Regulatng screw and wheel.

Figure 10. Air-exhaust valve, assembled and disassembled.

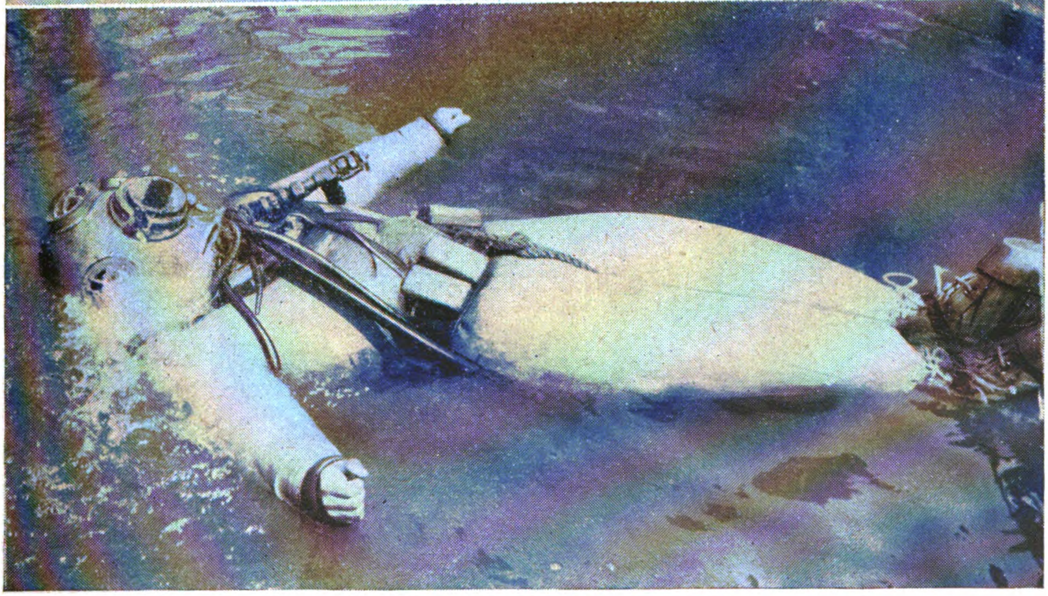


Figure 11. Diver blown to surface when air pressure in suit exceeded external pressure by more than two pounds.

is entirely closed, the valve stem is held against its seat by the 2-pound spring instead of the ½-pound spring and it is possible to build up a pressure of 2 pounds per square inch within the suit. This is ample to give the diver any degree of buoyancy he may require. Pressure difference between ½ pound and 2 pounds are maintained within the dress by the secondary valve spring, the amount of pressure desired being determined by the handwheel setting. The valve can be opened fully by depressing the chin button. Pressure difference above 2 pounds causes the diver's suit to blow up like a balloon. (See fig. 11.)

(7) When his suit is overinflated, it is impossible for the diver with his stiff arms to reach his air-exhaust or air-supply handwheels to adjust his air and the sudden change in pressure may cause him to be blown to the surface. A bad case of "bends" would be the best he could hope for and he might expose himself to more serious injury. The exhaust valve is helpful but it does not eliminate the possibility of blowing up.

(8) On the left side of the helmet is an auxiliary relief valve or spit cock. (See fig. 3.) This valve is open when the handle is in a horizontal position and closed when the handle is vertical. This valve is used principally when the diver is working on his right side and so is not obtaining the maximum benefit from his regulating exhaust valve. It also permits minor changes in buoyancy without disturbing the setting of the main exhaust valve. Moreover, should the faceplate fog, it is possible to take water into the mouth through the spit cock and use it to wash the faceplate.

d. Breastplate. (1) The helmet is worn on the breastplate which in turn rests on the breastplate cushion or the shoulder pad which goes around the diver's neck. (See fig. 12.) The breastplate studs fit into the holes of

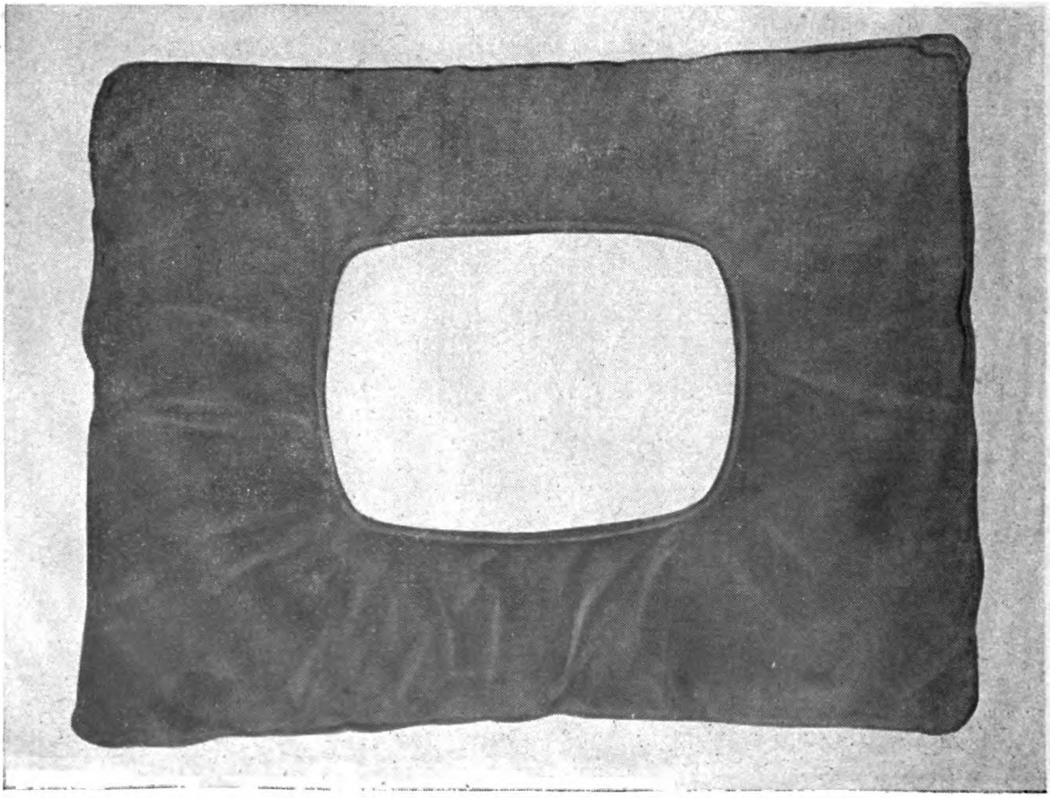
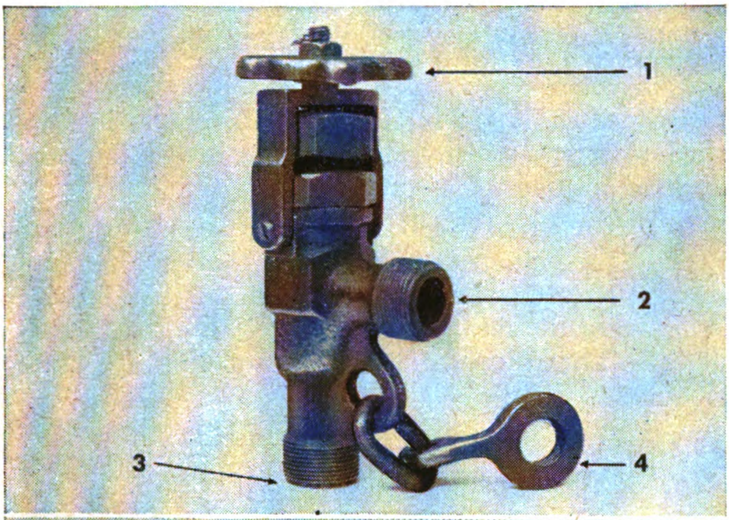


Figure 12. Breastplate cushion.

the breastplate collar. Before the clamps are placed in position, copper washers or shims are put on to provide an effective seal and to protect the rubber collar from chafing, pinching, or breaking. To seal the breastplate to the collar four breastplate clamps are used. These gun-metal strips are not interchangeable and are marked "front" and "rear." They are fixed to the breastplate with wing nuts.

(2) On the front of the breastplate are two pad eyes to which signal lanyards or Italian hemp lines are attached. (See fig. 3.) The lifeline is fastened to the right pad eye; the air line to the left pad eye.

e. Air-control valve. The air-control valve is a needle valve that controls the inlet of air to the diver's helmet. (See fig. 13.) The valve is held



1. *Air-regulating wheel.*
2. *Opening to helmet.*
3. *Opening to air hose.*
4. *Link and bracket chain.*

Figure 13. Air-control valve.

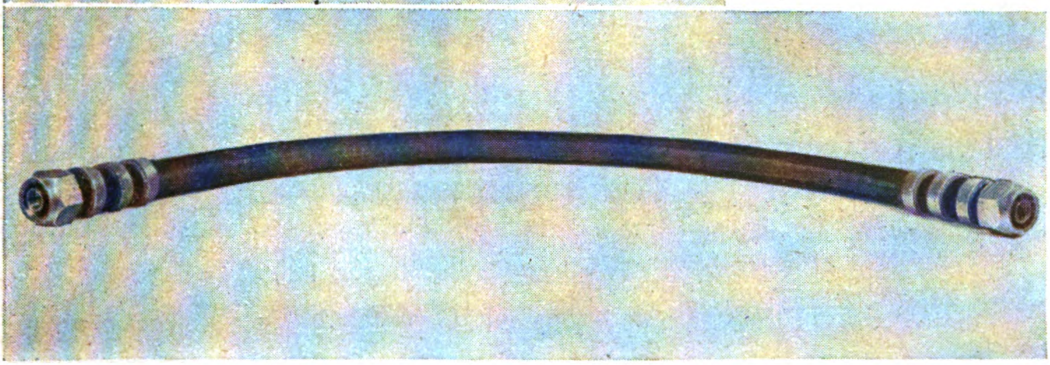


Figure 14. Whip (three-foot length of diver's air hose) connecting air-control valve to helmet.

to the diver's dress with a link-and-bracket chain that is placed under and is held by the wing nut on the long stud at the lower left-hand side of the breastplate. A whip (fig. 14) connects the valve opening at (2), figure 13, to the helmet. When the valve is in position and fastened to the diver's dress, the amount of air is increased by the diver turning the handwheel toward him, decreased by turning it away from him.

f. Weighted belt. The weighted belt furnishes negative buoyancy when the diver's dress is moderately inflated. (See fig. 15.) The lead weights are fastened to the belt with countersunk screws. The heads of the screws pass through spur grommets inserted in the leather to permit the weights to

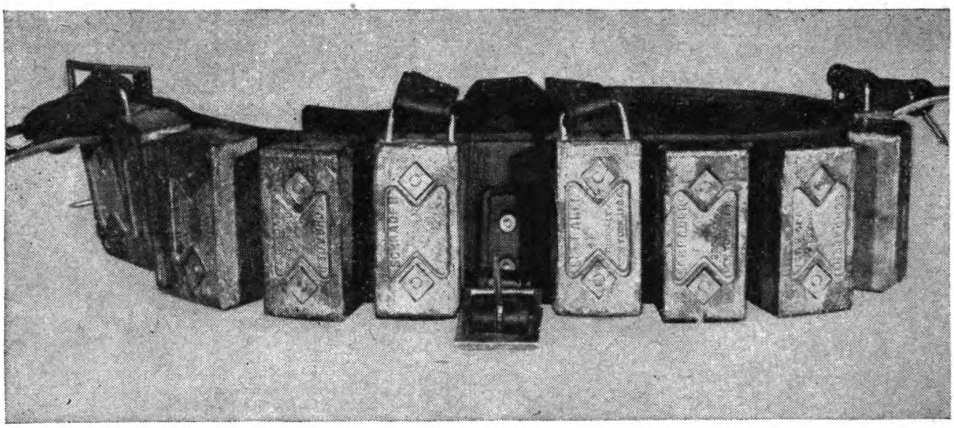


Figure 15. Weighted belt.

be fastened to the belt or removed easily. Metal strap hangers cast in four of the weights are attached to straps which pass over the breastplate and cross in back to hold the belt in position.

g. Diver's knife. A corrosion-resistant steel knife with one cutting and one sawing edge is attached to the belt. The sheath is made of brass and has a ¼-inch hole in its bottom to let water in and maintain the negative buoyancy of the knife. The top of the sheath is threaded to take the threads on the hilt of the knife blade. The knife handle is balanced so if the knife is dropped it will fall point down.

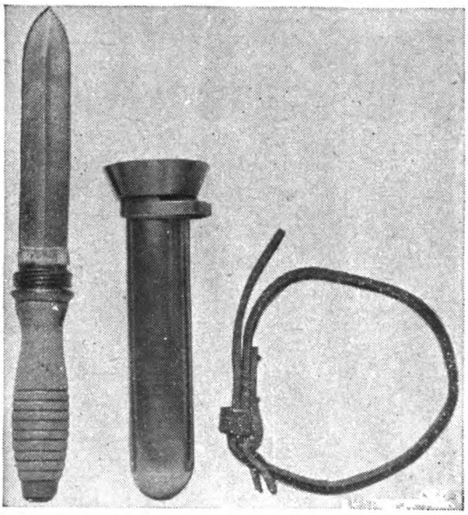


Figure 16. Knife, sheath, and belt.

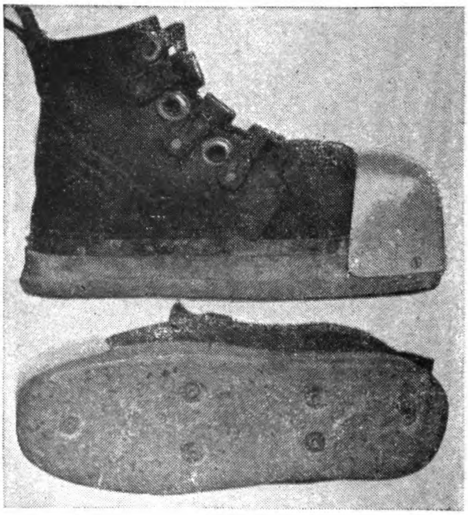


Figure 17. Diver's shoes.

h. Jockstrap. The jockstrap holds the diver's belt and shoulder straps in place. In this way the breastplate and helmet are held on the shoulders when the dress is inflated.

i. Shoes. (1) The shoes have lead soles, hardwood upper soles, leather uppers, and brass toe caps. A new type of shoe, similar to the leather shoes, but with canvas uppers is also used. They are constructed so any of the component parts, lead sole, wood sole, or canvas upper, may be replaced. (See fig. 17.)

(2) Each shoe weighs approximately 20 pounds and has the following dimensions:

Inside length	13 inches
Height inside of heel	6 inches

j. **Weight of diving dress.** The various items of the diving dress weigh as follows:

Helmet with breastplate	54 pounds
Shoes	35 pounds
Weighted belt and jockstrap	85 pounds
Dress	18½ pounds
Total weight	192½ pounds

k. **Diver's tool bag.** The diver's canvas tool bag is perforated to allow it to flood or drain rapidly. This bag can carry weights up to 200 pounds. When it is loaded lightly it is carried over the right arm; when heavily loaded it is sent down the descending line. (See fig. 18.)

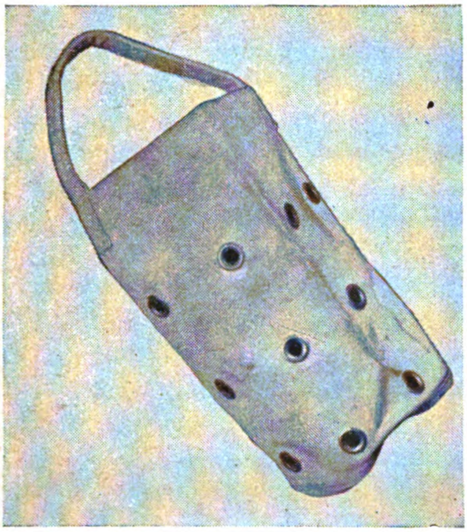


Figure 18. Diver's tool bag.

Figure 19. Morse diving light. (This light has a 1,000-watt lamp that can withstand pressure at 500-ft. depths.)

11. DIVING EQUIPMENT. a. Diving ladder. The diving ladder is designed for use over the sides of barges, floats, or motor launches. It is adjustable and may be used to fit launches up to 50 feet long. It is made of heavily galvanized wrought iron and may be folded after use to facilitate storage.

b. Diving light. Underwater vision varies from 0 to 50 percent of normal and is one of the greatest handicaps experienced by divers. In turbid water or on extremely muddy bottoms, the diver works in almost total darkness and depends mostly on his sense of touch to identify objects. The light adopted for Army use is the Morse light. See figure 19. The light has a 1,000-watt lamp, a lamp holder of seamless brass tubing, and a chromium-plated copper reflector fitted with a wire-meshed guard. Diving lights are never lighted in air as the heat the lamp generates burns out the bulb filmament quickly. The light is submerged before lighting and the current is turned off before the light is hoisted from the water.

c. Lines. Lines used in diving and salvage operations are those extend-

ing from the surface to or close to the diver. In general, they are as follows:

(1) *Descending lines.* Descending lines are used by the diver to reach the bottom. In rescue and salvage work, a descending line is usually attached to the wreck by the diver. This line is then used to reach the desired point on the wreck. For ordinary diving, the descending line is weighted and lowered directly to the bottom. Standard descending lines are made of 3-inch circumference manila rope. They are 200 feet long and are cable-laid to prevent twist.

(2) *Distance lines.* Distance lines are made of cable-laid manila rope 60 feet long. The line is fastened onto the descending line just above the weight and is used by the diver in rotary searching and as a guide for relocating the descending line when he is ready to ascend.

(3) *Hauling lines.* Hauling lines may be either wire or manila rope and are used in lifting or moving heavy objects on the bottom.

(4) *Lowering lines.* Lowering lines vary in size and are attached to objects being sent to the bottom.

(5) *Stage lines.* Stage lines are made of 3- and 4-inch manila rope and are used to raise and lower the diving decompression stage. Two 3-inch lines 112 feet long are used for the small stage. The lines are marked at 10-foot intervals to correspond to decompression stops, the first mark being located 10 feet above the stage platform. The lower ends of the lines have thimbles or shackles for attaching the lines to the slings of the stage. For the larger stage, one 4-inch manila line is used. Stage lines are marked to indicate the depth of submergence of the stage:

Feet	
10	1 cloth tag (red)
20	1 cloth tag (yellow)
30	1 cloth tag (blue)
40	2 cloth tags (red)
50	2 cloth tags (yellow)
60	2 cloth tags (blue)
70	3 cloth tags (red)
80	3 cloth tags (yellow)
90	3 cloth tags (blue)
100	4 cloth tags (red)
110	4 cloth tags (yellow)
120	4 cloth tags (blue)
130	5 cloth tags (red)
140	5 cloth tags (yellow)
150	5 cloth tags (blue)

d. Oil separator. Oil separators prevent oil that the air may carry over from the pumping system being blown into the air hose. The separator has two bronze cups screwed together against a leather gasket. (See fig. 20.) The air current within the separator is directed by a baffle through a loofah or cellulose sponge which filters the air before it enters the air hose.

e. Diving decompression stages. The small diving stage has an 18- by 36-inch platform; the platform of the large stage is 48 by 60 inches. Both stages are identical in construction, varying only in size.

f. Telephones. (1) *General.* Dry-cell battery, storage battery, batteryless, and amplifier types of telephones are used. The amplifier type of communication gives the most satisfactory results and is used for military diving. This equipment is known as diving-amplifier equipment and consists of the

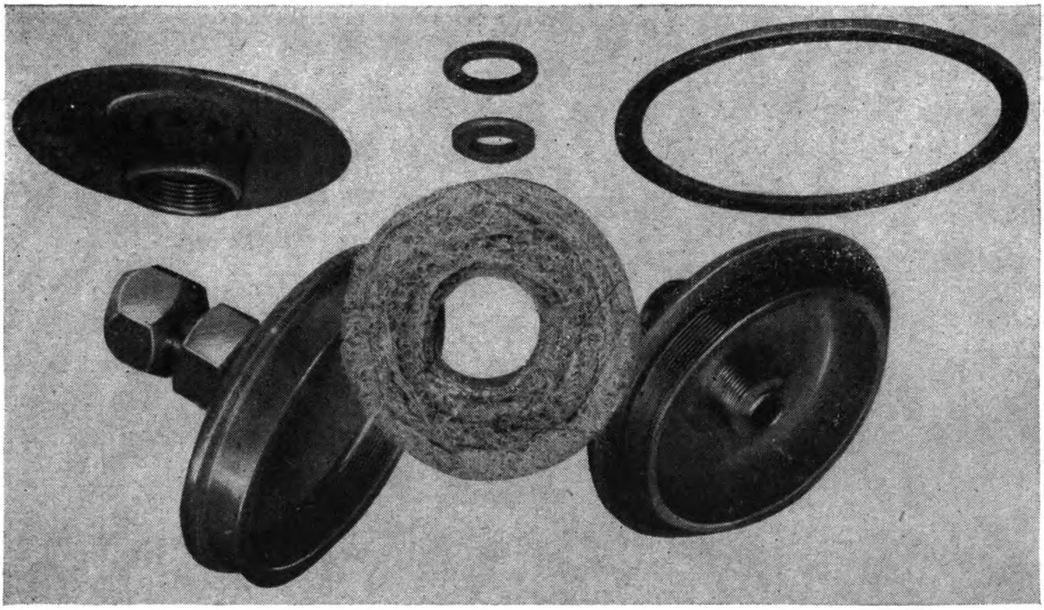


Figure 20. Oil separator disassembled. (This separator prevents oil from being blown into the air hose.)

diving amplifier, the diver's transmitter reproducer unit, the power cables, and the combination diving-amplifier and life-line cable.

(2) *Diving amplifier.* (fig. 23.) The diving amplifier is the heart of the system in that it amplifies the voice in each direction and provides two-way speech from the tender to a maximum of three divers. It will operate on any one of three types of power: 110-volt, 60-cycle, single-phase a-c; 110-volt d-c; or 12-volt d-c. It has one channel so arranged that all divers may talk to the tender at any time except when one of the talk-keys is depressed. Figure 24 shows the tender talking to No. 3 diver. If the tender wished to give the same message to all the divers he would depress the three keys. Two tone and two volume controls govern the frequency response and volume for speech in each direction.

(3) *Diver's transmitter-reproducer unit.* The diver's unit is a permanent-magnet loudspeaker that serves both as transmitter and reproducer. The unit equires two wires from the tender to the diver. It is mounted in the diver's helmet and is suspended in rubber cushions. (See figs. 9 and 25.)

(4) *Power cables.* Three 30-foot power cables are supplied with the equipment. Each has a special polarized plug and is marked for the type of power supply with which it is to be used.

(5) *Combination diving-amplifier and life-line cable.* Standard diving cable is supplied with the amplifiers. It is furnished in 200-foot lengths and consists of a central core to give it strength for hoisting purposes, a rubber core jacket, four electric wires insulated with a 1/32-inch rubber jacket, and an outer cover of tough rubber. The cable is ⅝ inch in diameter, weighs about 0.35 pounds per linear foot, and has a breaking strength of approximately 2,500 pounds. Each length of cable has two special brass plugs and one coupling. The plugs are attached permanently to each end of the cable and make a strong, watertight mechanical connection and a positive electrical connection to the diver's amplifier. When additional cable length is needed, the coupling connects two or more 200-foot lengths.

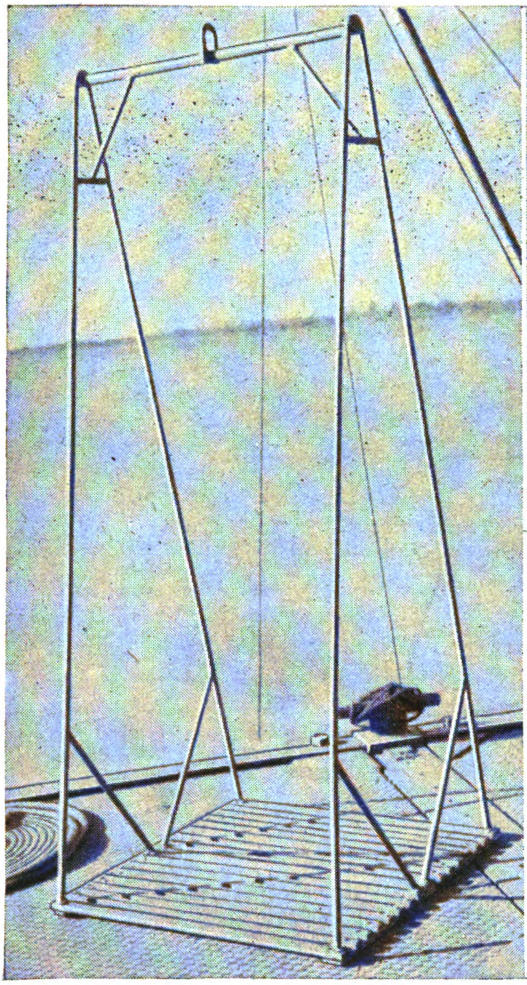


Figure 21. Diving decompression stage.

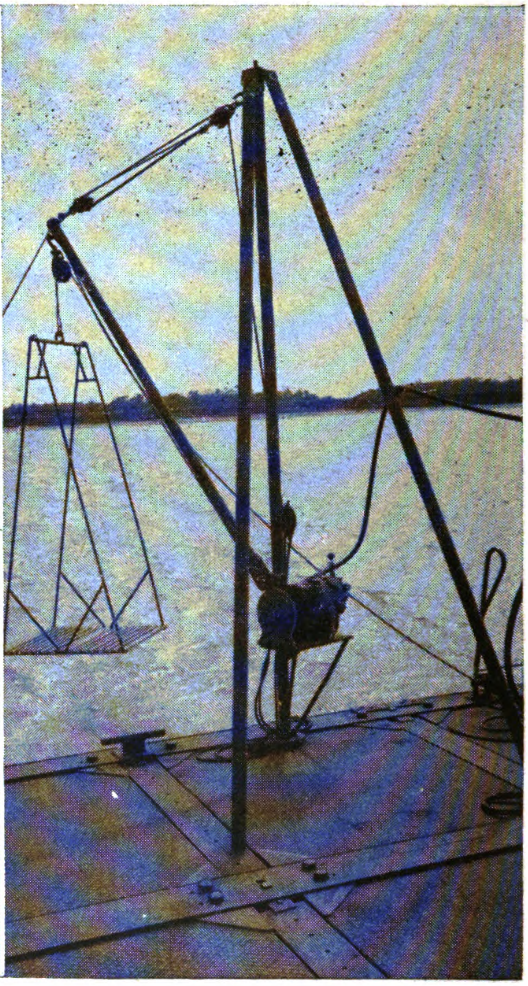


Figure 22. Diving decompression stage ready for lowering over side of diving float. (The small decompressed-air winch is mounted on vertical leg of tripod and raises and lowers the stage.)

g. Recompression chamber. The recompression chamber has three functions:

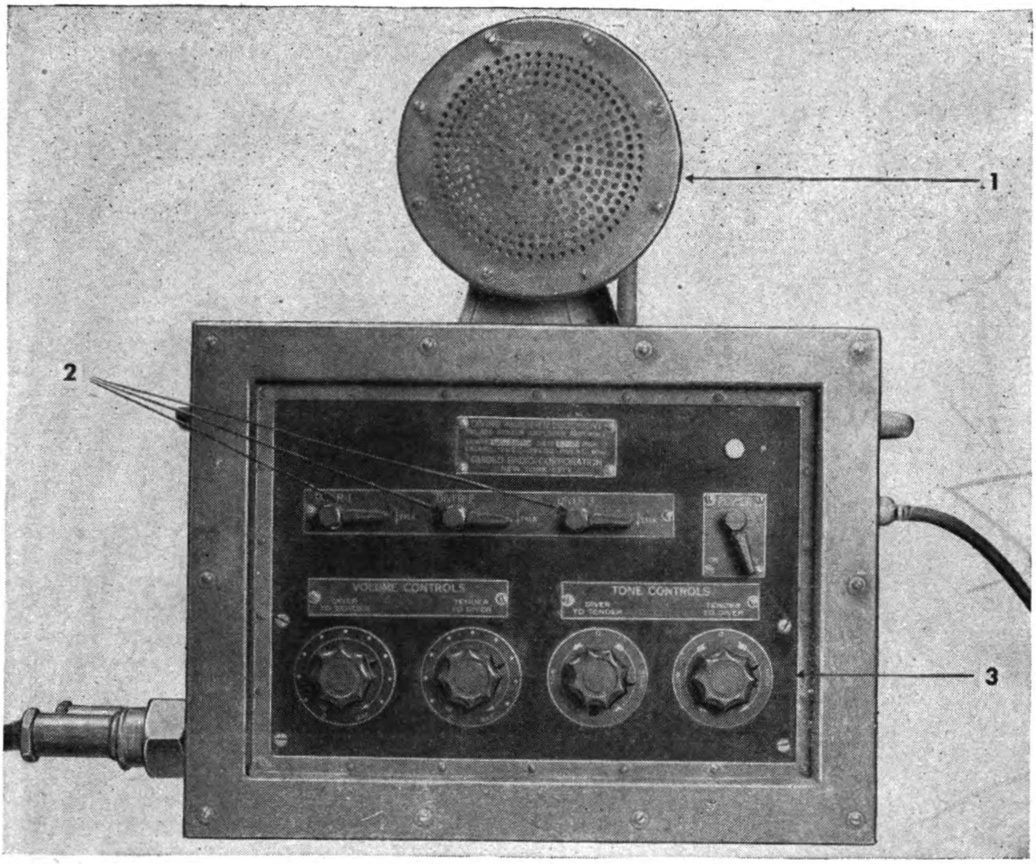
(1) Treatment by recompression of victims of the bends.

(2) Decompress divers when it is impossible or dangerous to do so in the water.

(3) Accustom personnel to pressure to determine their ability and fitness to withstand pressure. The standard recompression chamber is designed for working pressure not exceeding 200 pounds per square inch. It is kept ready for instant use at all times while diving operations are underway and for at least 15 hours after the divers have ascended. (See figs. 26 and 27.)

h. Air compressors. For deep sea diving, large power-driven compressors with receiving tanks are used. For information concerning their operation and maintenance, refer to the manufacturers' operator's manuals.

(1) Diving between 36- and 80-foot depths does not require large compressors. Portable, light-weight, gasoline-driven air compressors have been developed for diving at these depths. (See fig. 28.)



1. Tender's transmitter–reproducer.
2. Three receptacles.
3. Control panel.
Figure 23. Diving amplifier showing.

Figure 24. Tender talking to No. 3 diver.

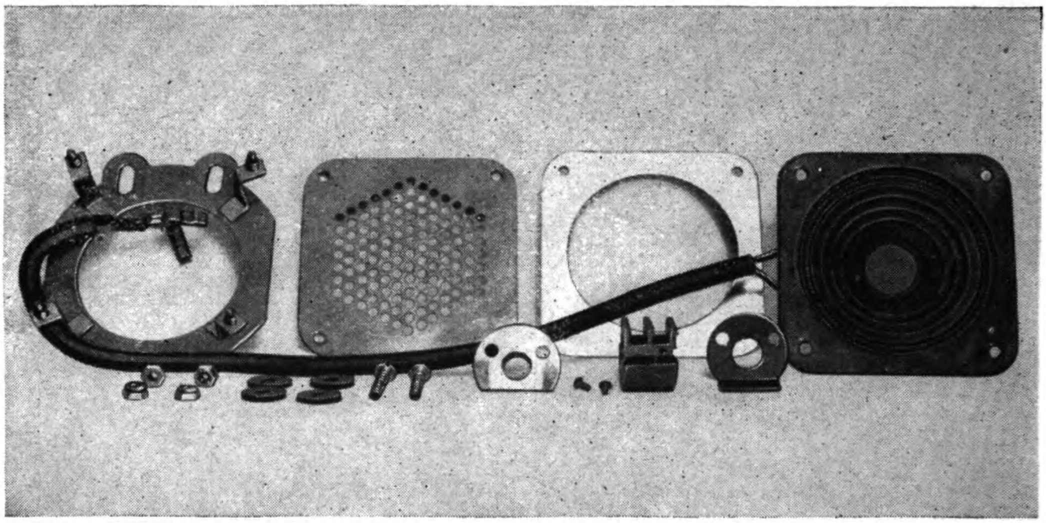


Figure 25. Diver's transmitter-reproducer unit, disassembled.

(2) The portable compressor delivers air in ample volume for diving up to 80 feet. The unit is mounted in a large-diameter tubular frame which holds a reserve air supply. (See fig. 28.) Its gasoline engine is a single-cylinder, four-cycle, aircooled type, and develops 1.9 hp at 2,400 rpm. Refer to manufacturer's operator's manual for operating and mantenance instructions.

i. Blowing hose. Blowing hose is used for blowing and venting air to and from underwater compartments and tanks. Usually, 1¼-inch diameter pneumatic air hose is used for this purpose, but the ½-inch diameter diving hose may be used if the larger size is not required.

12. SHALLOW-WATER EQUIPMENT. a. General. The Army is doing research work and is experimenting with several types of shallow-water diving gear. The equipment manufactured by Ohio Rubber Company is standardized and is now being issued. This paragraph describes that equipment only. It consists of a rubber face mask, a nonreturn valve, two pairs of divers' underwear and rubber sneakers, one 50-foot length of air hose, one 3-foot length of air hose, an expansion tank, and a manually operated pump. (See fig. 29.)

b. Face mask. The face mask is a molded rubber facepiece held to the face with rubber straps. The eyepieces are of tempered glass. A "demand" type breathing valve on the front of the mask is so designed that with a constant air supply of 90 pounds pressure it opens only when the diver inhales. On exhalation, the valve remains closed. A push button on the valve may be used to open the valve to let additional air into the mask quickly. The air-supply line is connected to the demand valve. A bypass valve permits the diver to receive a continuous flow of air. The mask may be used without the "demand" valve by connecting the air hose directly to the air fitting on the mask. Connected this way, the exhaust air escapes around the edges of the mask. To retain the diver's air supply in the mask if the air is severed, a safety nonreturn valve is placed in the air line between the demand valve and the hose coupling. (See fig. 30.)

Figure 26. Men in recompression chamber.

c. Volume tank. When the manually operated shallow-water pump is used for air supply, an expansion tank is required to eliminate the variable pump-stroke pressures.

d. Pump. The air pump is a two-cylinder, single-action, manually operated pump, weighing approximately 62 pounds. The cylinder block is fastened to a plank of sufficient length to extend about 12 inches beyond one end of the block. (See figs. 31 and 32.)

13. MAINTENANCE OF DIVING EQUIPMENT. a. General. All diving equipment must be kept in good repair and ready for immediate use. When new equipment is received it is carefully inspected and tested. Thereafter, frequent inspections are made to determine its condition and all ncessary repairs are made at once. Gear is stowed in accessable places and away from excessive heat. When there is space, it is kept under cover. If this is not possible, canvas covers are used to protect equipment from the weather. Spare parts not needed for immediate use are kept in suitable storerooms. Requisitions are submitted at once to replace any part drawn for use.

b. Leather. Leather used in water must be properly cared for to prevent its becoming dry, hard, and brittle.

(1) Neat's-foot oil, well rubbed in, preserves the leather.

(*a*) Spread the leather as flat as possible.

(*b*) Soak a rag in oil and apply one coat at a time until the oil soaks through to the other side.

(*c*) Do not oil both sides at once.

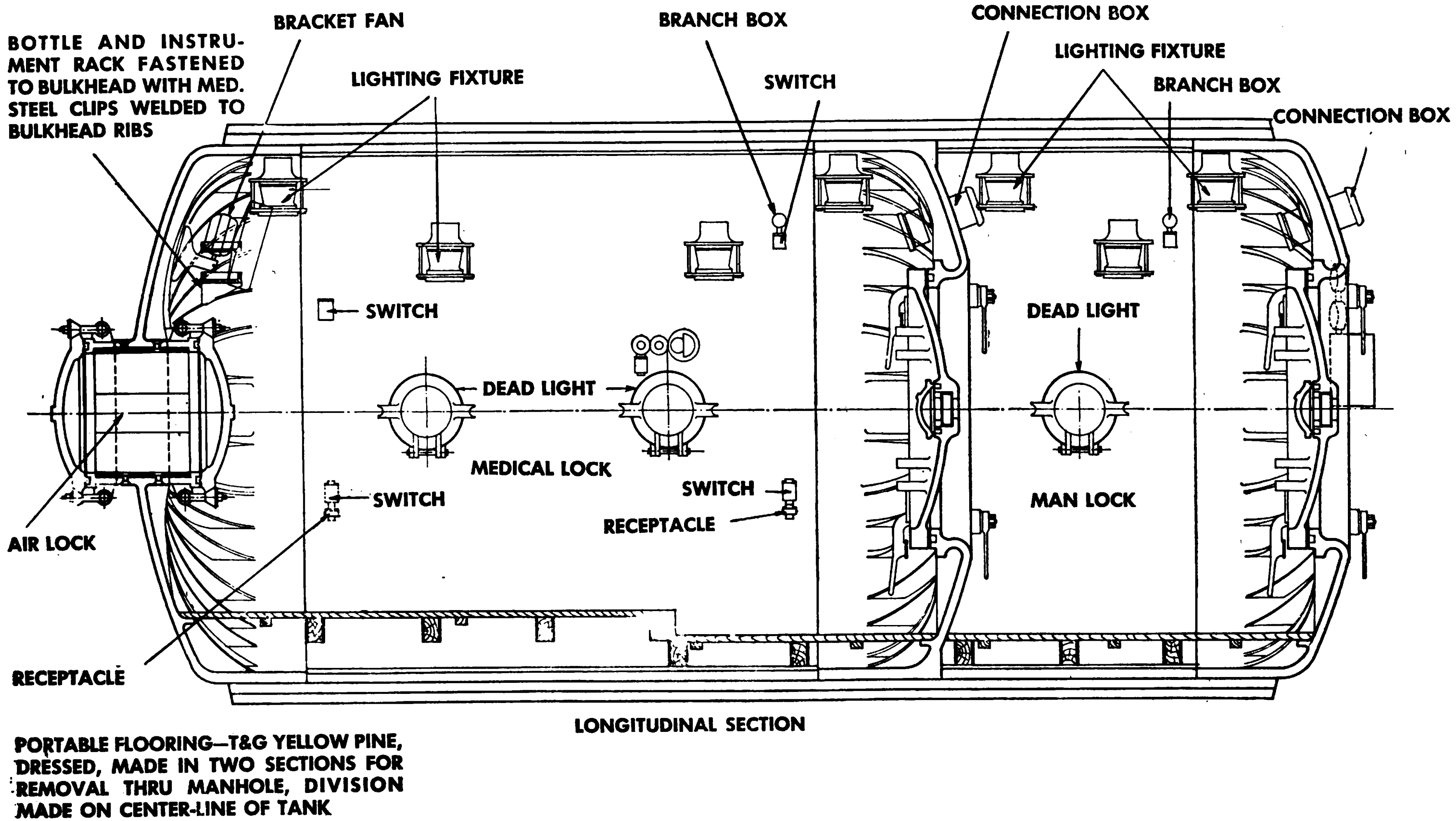


Figure 27. Longitudinal cross section of recompression chamber.

(*d*) Never try to treat by submerging the leather in oil.

(2) After a diving belt has been used, dry it thoroughly. Clean the buckles and give them a light coat of oil. Treat the belt and strap with neat's-foot oil if necessary. Deterioration cannot always be discovered by visual examination, so an actual test of the belt is necessary. The belt is buckled and a man weighing about 160 pounds gradually puts his weight on the straps. A defective belt is replaced immediately.

c. Metal parts. All metal parts must be kept free of rust and verdigris. Special care is taken with valves, valve seats, and similar parts to keep them in good working order and protected from injury. A light coat of oil is applied to all parts not painted, polished, or galvanized.

(1) Helmets are kept screwed to their respective breastplates, with the wing nuts lightly screwed onto the studs to prevent damage to the threads.

(2) When in the diving boat but not in actual use, helmets are placed right side up on the helmet track to keep them from being knocked around and to protect the internal telephone unit from dampness.

(3) Before being stowed away, the helmets are wiped with a dry cloth, inside and out, to prevent accumulation of moisture and consequent rusting of the telephone diaphragm. The blank cap is screwed onto the telephone gooseneck.

(4) Faceplate lenses are checked to see that they are not cracked, and that they are firmly embedded in the red lead and litharge seat.

d. Rubber. Rubber parts of diving apparatus have a definitely stipulated

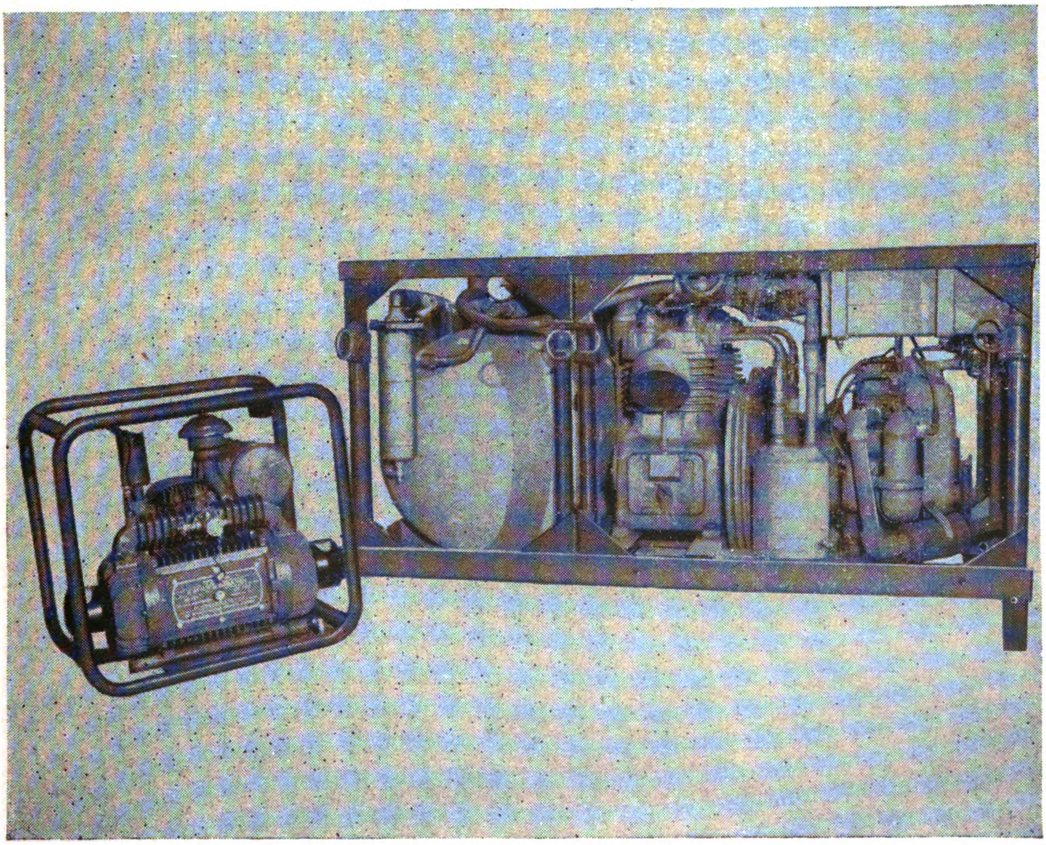


Figure 28. Small, portable compressor at left shown with large compressor with receiving tank at right.

period of usefulness. However this can be shortened if the parts are not properly cared for.

(1) Oil or grease is especially destructive to rubber, so all rubber diving equipment must be protected from these substances.

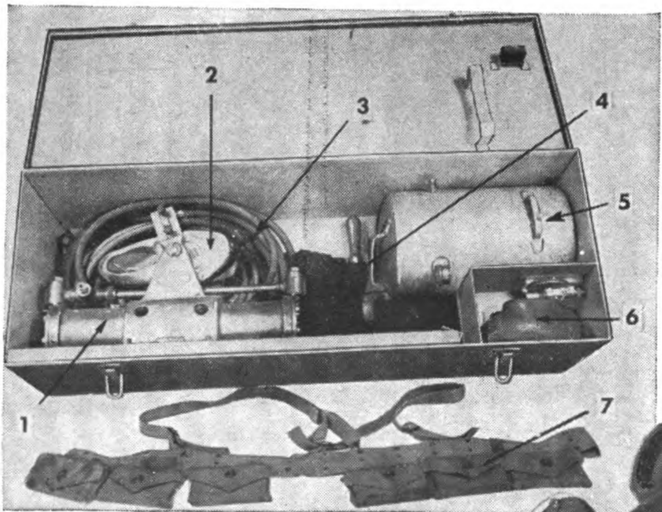
(2) Rubber and rubber-covered parts must not be stored until after they have been thoroughly dried.

(3) Folded rubber materials acquire a permanent set at the bend, and when used are liable to crack or break open at these points. As far as is practicable, therefore, they are stored without folding.

(4) Before using any new parts, those with the oldest manufacture date are used until they become unserviceable or reach their age limit.

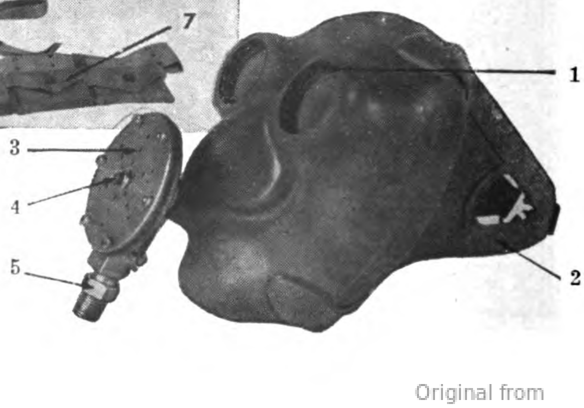
(5) When particularly rough work is to be done, the diving dress is protected by canvas overalls, or chafing pants worn over it. After use the dress is thoroughly dried. If it has any odor, it is washed inside and out, turned inside out, and hung in the shade to dry. Then it is turned right side out, dried, and put away. After use in salt water, the dress is washed in fresh water. A drying frame can be made of two 8-foot long battens joined in the shape of an ×. (See figs. 33 and 34.) This frame is put inside the dress and another batten is passed through the arms. The dress is leaned at a slight angle until it is dry.

(6) New hose is examined before using to make sure there is no soapstone inside. When coupling lengths of hose together, a leather washer is always placed in each female coupling. Hose deteriorates rapidly, particularly if it is stored in a hot place. Therefore, if a hose has been in storage for some time, it must be tested before being used. The test pressure, at least 50 percent greater than the maximum pressure of the dive, is maintained for 30 minutes. The date of manufacture is molded into the hose. Two years after that date, the hose is hydrostatically tested for 30 minutes at a pressure of 187.5 pounds per square inch and momentarily at 750 pounds pressure. The same test is repeated after $2\frac{1}{2}$ years. Hose over 3 years old is not used for diving.



1. Hand pump.
2. Rubber sneakers.
3. Air hose.
4. Diver's underwear.
5. Expansion tank.
6. Face mask.
7. Weighted belt.

Figure 29. Ohio Rubber Company shallow-water-diving equipment.



1. Eye piece.
2. Rubber straps.
3. "Demand" valve.
4. "Demand"-valve pushbutton.
5. Nonreturn valve.

Figure 30. Face mask, Ohio Rubber Company type.

Figure 31. Ohio Rubber Company shallow-water outfit, showing diver ready to go down with life line.

Figure 32. Ohio Rubber Company equipment—front view.

e. Cotton and woolen goods. Cotton and woolen goods are kept clean, dry, and in usable condition. When not in use they are treated with napthalene or a similar larvicide and wrapped tightly in paper. Dirty woolens are washed with soap and lukewarm water, rinsed thoroughly, and dried.

f. Chests. Helmet and outfit chests are kept clean inside and out. Exterior brass is kept clean and polished, and iron work is kept rustfree, painted, and enameled.

g. Power-driven air compressor. Maintenance and repair instructions for the power-driven air compressor are issued with each unit.

14. REPAIR OF DIVING EQUIPMENT. a. Patching. A repair outfit for patching rubber gear is furnished with diving outfits. Figure 35 shows repair equipment including a roll of repair cloth and patches of various shapes, shears, mallet, rubber cement, and a wooden plug for repairs to cuffs.

(1) Leaks and tears in the diving dress are repaired as follows:

(*a*) Clean the defective portion, remove all traces of dirt and grease, and roughen surface with sandpaper, emery cloth, or wire brush.

(*b*) Apply three coats of rubber cement with small, clean paint brush. Allow each coat to dry for 45 minutes before applying next one (See fig. 36.)

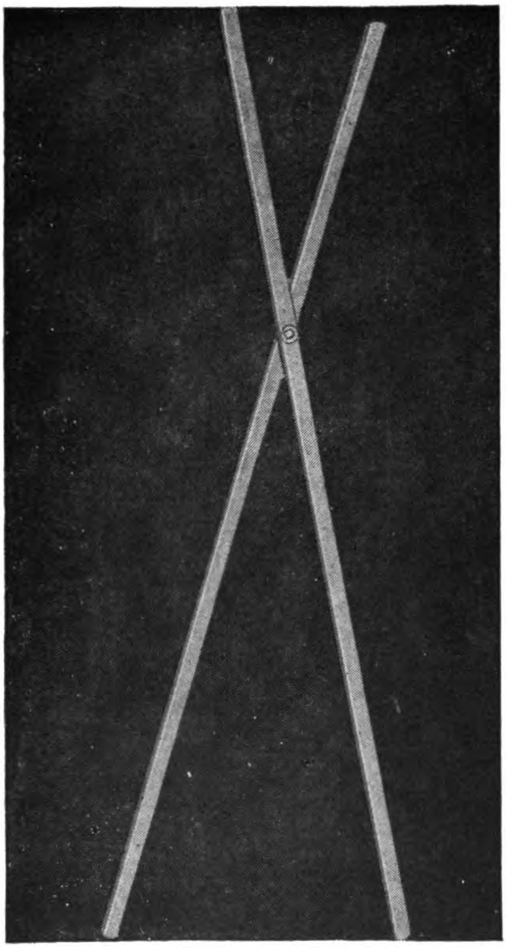


Figure 33. Drying frame for diving dress.

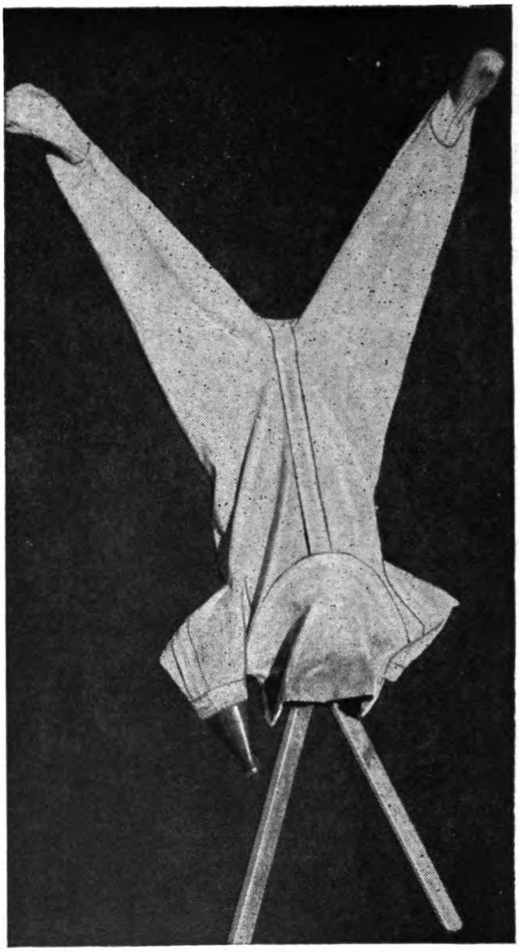


Figure 34. Diving dress shown on drying frame.

(*c*) Prepare patch by cutting a piece of repair cloth 1 inch larger on all sides than area to be repaired. Remove protecting cloth from patch, using benzine to loosen it. Swab exposed surface with benzine and tack to flat board to prevent curling.

(*d*) Apply coat of rubber cement to patch and allow it to dry for 45 minutes.

(*e*) Place an edge of the patch on rubber-cemented portion of dress and work patch gradually onto dress. Use fingers to remove all wrinkles and air bubbles. (See fig. 37.)

(*f*) Use hand roller, flatiron, or mallet to press patch down firmly. (See fig. 38.)

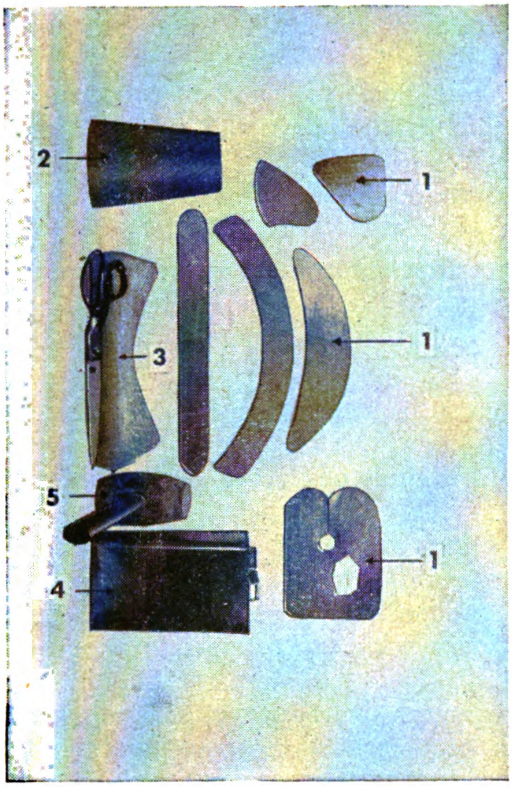
(2) Tears in the collar of the diving dress usually occur around bolt holes. Sew tear together with herringbone stitches and fill needle holes with rubber cement. After rubber cement dries, cement patch inside and outside of damaged hole.

(3) When collar is so badly damaged as to require replacement, dress is sent to a higher echelon.

(4) To repair a glove—

(*a*) Remove worn fabric.

(*b*) Cut patches to pattern of damaged section.



1. Patches
2. Wooden cuff plug.
3. Repair cloth.
4. Rubber cement.
5. Wooden mallet.

Figure 35. Diving dress repair material and equipment.

Figure 36. Applying rubber cement to dress before putting on patch.

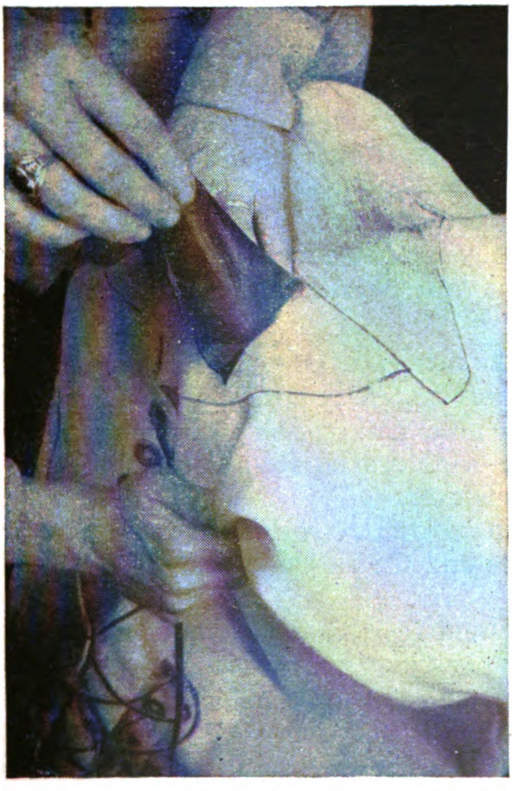


Figure 37. Applying patch to dress.

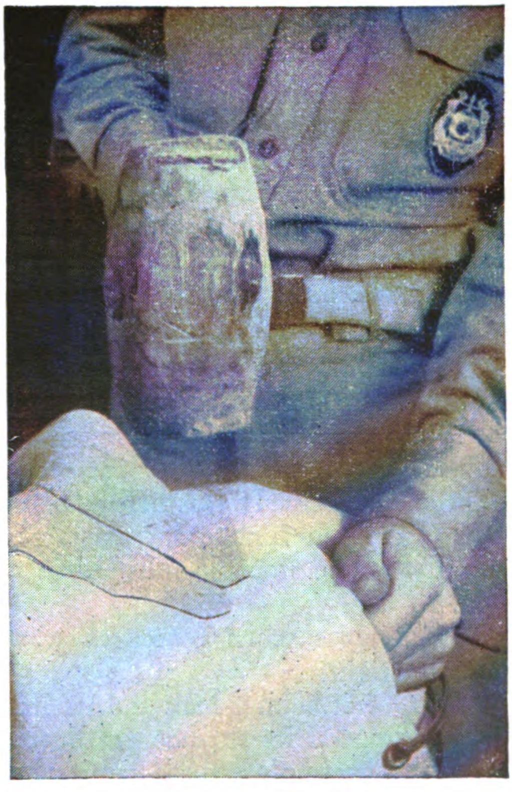


Figure 38. Using mallet to press patch firmly to dress.

(*c*) Prepare both patch and rubber surface of glove with cement at same time. Procedure is same as for patching dress, (1) above.

(*d*) An assistant puts gloves on and half closes his hand to conform to molded curvative of glove. Apply thumb patches first and smooth them into place. Next apply palm patches.

(*e*) Clip off rough edges of patches, remove glove, and allow patches to set 48 to 72 hours before using.

b. Attaching cuffs to dress. Cuffs are attached to dress in the same manner as a patch is applied. If necessary, edges of the cuff are recemented. A thin strip of repair cloth is cemented on over the line where cuff joins the sleeve.

c. Attaching gloves to dress. Gloves can be attached to the diving dress in the following manner:

(1) Remove cuffs, insert wooden plugs in ends of sleeves, and clean and roughen 2 or 3 inches of sleeve.

(2) Cut wrist off gloves as follows: 1 inch for No. 1 dress, 2 inches for No. 2 dress, and 3 inches for No. 3 dress.

(3) Stretch gloves over sleeve plugs and pull them up so 2 or 3 inches overlaps sleeves. Line up thumbs of gloves with top or outside seams of sleeves.

(4) Roll back portion of gloves that overlaps sleeves; clean and roughen.

(5) Prepare gloves and sleeves with cement at same time, and when cement has set, roll turned-back portion of gloves onto sleeves and allow 48 hours for cement to set.

(6) When it has set, cut and prepare 2½ inch wide strips of repair cloth, and fit them over joints of glove and sleeve, with ends of strips overlapping about 2 inches.

(7) Allow this to set for 48 hours, turn suit inside out, and seal inside joint strips as in (6) above.

(8) Do not use suit for the next 48 hours unless an emergency makes it necesasry.

d. Repairing hose. Sometimes attempts are made to repair hose by cutting out defective places and recoupling the good sections. This practice is not approved. Ends of diving hose as issued are water-tight because of a cap of 1/16-inch thick layer of rubber compound. When hose is cut to eliminate a bad section, the ends cannot be made watertight. Water seeps in along the braid and inner tube of the hose, weakening it and making it dangerous to use.

e. Repairing the helmet. Keeping the helmet in safe operating condition is primarily a process of frequent and thorough check-ups.

(1) Examine faceplate hinges, hinge pins, gasket, and knife edges, and replace any defective parts. If seat for wing nut on front faceplate is not countersunk, remedy this before helmet is used.

(2) Tighten functioning parts of spit-cock valve so it cannot open accidentally. The stop pin must be in place and the air duct clear when valve is open.

(3) Replace worn gooseneck washer and see that telephone connections are watertight.

(4) Check helmet lock and its stopgap and replace if defective. Replace bayonet joint if its threads are burred.

(5) If breastplate neck-flange gasket does not seat evenly, install a new one.

(6) Replace any nuts on breastplate studs that do not turn and tighten freely. Straighten any bent breastplate straps.

(7) Check lanyards and replace those that are worn.

(8) As a result of wear, a helmet may screw onto its breastplate so far that the safety locking catch passes its recess and the faceplate does not come directly in front of diver's face. Repair this by replacing neck-flange gasket or by cutting one or more paper washers and inserting them under the old one.

(9) Disassemble, clean, and oil safety valve frequently. Make certain that leather valve disk and spring are in good condition. If valve is dirty, the spring weak, or follower nct screwed all the way down, it does not work freely or seat itself smartly when pressure is released. Check the inside diameter of gasket between valve and gooseneck. Sometimes when valve is tightened, gasket spreads and overlaps into air passage, restricting diver's air supply. Test valve after it is reassembled by screwing it backwards onto a length of hose, attaching hose to a compressor, and applying pressure. Immerse valve in water and watch for bubbles. If there are none, valve is watertight; if there are bubbles, it leaks and leather valve disk or spring must be replaced.

(10) The air-regulating exhaust valve also requires frequent disassembly and cleaning. Check secondary spring to see that it opens when pressure on seat is 2 pounds more than outside pressure.

(11) Adjust packing of air-control valve so valve works stiffly enough to prevent accidental opening or closing, but freely enough so diver can manipulate it.

SECTION IV

AIR SUPPLY

15. GENERAL. a. Basic considerations. Air supply is the most important factor in diving operations. A diver at work breathes out 0.045 cubic feet of carbon dioxide (CO_2) per minute. All this CO_2 is discharged into the confined space of his helmet, and unless the concentration is kept down by constant addition of fresh air, the diver will suffocate. The safe limit of CO_2 concentration at atmospheric pressure is 3 percent. The minimum air supply needed to keep CO_2 within that safe limit is 1.5 cubic feet per minute.

b. Computing air supply. To compute air supply using the safety factor of 3, the following formula has been derived.

$$S = 0.13635\ D + 1.5 \times 3$$

Where: S is the supply of cubic feet of air per minute required by a diver at any given depth

D is the maximum depth in feet to which he will descend

1.5 cfm is the minimum safe air supply

3 is the safety factor

For example, a diver is to work in 33 feet of water. How much air will he need?

$S = 0.13635 \times 33 + 1.5 \times 3$

$S = 4.49955 + 4.5$

$S = 8.99955$; 9 cubic feet of air per minute is required

c. Sources of diver's air supply. (1) Air is normally supplied to the diver by one of the following:

(*a*) Power-driven compressors.

(*b*) Hand-driven compressors.

(*c*) Air flasks or other containers.

(2) In the past, castor oil was the only oil approved for use in diving air compressors. However, castor oil has become a critical item and tests have been conducted on other oils. The most satisfactory substitutes are:

(*a*) Neat's-foot oil.

(*b*) Mixture of equal parts of neat's-foot oil and olive oil.

(*c*) In an emergency, high-grade lubricating oils can be used although some produce unpleasant odors.

16. POWER-DRIVEN COMPRESSORS. a. Types. Ordinary compressors are either single-stage or two-stage. A single-stage compressor has one or more primary pistons; a two-stage compressor has in addition one or more secondary pistons. A secondary piston is a booster to increase the pressure of the air output; it does not increase the volume of output. The three types of power-driven compressors in use are:

(1) The Dapco compressor is a workable oilfree compressor used for military diving. It is light and easy to handle. Since it does not have a large volume tank, an air flask or another compressor should be held in reserve.

(2) DeVilbiss compressor, less satisfactory. It is issued in limited quantities.

(3) Other gasoline or Diesel engine-driven compressors. These usually pollute the diver's air supply with oil and fumes.

b. Precautions in use of compressors. When using a power-driven compressor, care must be taken to see that—

(1) It is securely fastened.

(2) It is kept in good operating condition.

(3) The air intake is not placed near an exhaust pipe, smoke stack or anything else that might pollute the diver's air supply.

(4) The compressor is not used for diving to depths greater than its rated capacity.

(5) Instructions regarding lubrication are rigidly followed.

(6) If the tank is not large enough to meet a possible emergency, another compressor or an air flask is connected to the line, ready for instant use.

(7) When oxygen (see par. 40d) is used as an emergency supply to a compressor, a stop or check valve is connected into the line so the oxygen will not back up and mix with the oil and cause an explosion.

(8) The compressor is never stopped while the diver is wearing his helmet.

(9) At least one compressor operator is trained to make instant repairs in case of emergency.

c. Measurement of output. The output of a compressor is the amount of cubic feet of air per minute it can supply to the diver. It is computed in the following manner:

(1) Find the output per stroke by multiplying the area of the bore in inches ($B^2 \times 0.7854$) by the length of stroke in inches (S), and dividing by 12^3 to convert to cubic feet.

$$\text{Output per stroke} \doteq \frac{B^2 \times 0.7854 \times S}{1{,}728} = B^2S \times 0.0004545$$

(2) Multiply that by rpm to find the output per piston.

(3) Multiply by the number of primary pistons (N).

(4) This gives the output for a compressor operating at 100 percent efficiency. No compressor is that efficient; they range from 90 percent when in good condition to 70 percent when in need of overhaul. When the efficiency of a compressor is not known the average figure, 80 percent, is used.

(5) The complete equation is:

$$\text{Output} = 0.0004545\ B^2S \times \text{rpm} \times N \times \%\ \text{efficiency}.$$

For example, find the output of a 90 percent efficient compressor with two primary pistons, 5-inch bore, 6-inch stroke, running at 700 rpm.

$$\text{Output} = 0.0004545 \times 5^2 \times 6 \times 700 \times 2 \times .90$$

Multiplying, we find the output is 85.9 cubic feet of air per minute.

17. HAND-DRIVEN COMPRESSORS. a. General. Standard hand-operated compressors have only a small capacity. The rate of pumping is limited and as pressure is built up, pumping becomes increasingly difficult. The maximum pumping rate that a crew can maintain for any length of time is 30 rpm. When this equipment is used, a diver can work only in comparatively shallow depths. These compressors are used mainly in skin diving or in shallow water when operating a power-driven unit is impractical. They are also employed in emergencies when other sources of air supply fail. If a greater supply of air is required or if it becomes necessary to dive to greater depths, two or more units can be connected to provide the required volume and pressure of air. A hand-operated compressor is never used to supply more than one diver except—

(1) In emergency when a relief diver is sent down and no other air supply is available.

(2) For shallow water diving at depths under 36 feet.

b. Precautions in use. Before diving operations start, the compressor must be checked carefully.

(1) Tighten pump-handle nuts with wrench.

(2) Examine bearings to make sure they are properly oiled.

(3) Give compressor a test run.

(4) Connect diver's air hose to an oil separator, not directly to compressor.

(5) Add water to cistern to cool air supplied to diver. During operation, add more water periodically.

(6) Follow lubrication instructions closely.

c. Computation of output. The rate of pumping should be controlled so the compressor supplies the diver with as close to the desired output of 4.5 cubic feet of air per minute as possible. The supply must never drop below 1.5 cubic feet per minute. The following formula is used to find the number of rpm required:

$$X = \frac{0.0303 \times R \times D + R}{E}$$

Where X is the number of rpm required to furnish 1.5 cubic feet of air per minute to the diver

0.0303 is the depth coefficient

R is the number of rpm required to deliver 1.5 cubic feet (2,592 cubic inches) of air per minute at atmospheric pressure. It is equal to 2,592 divided by N

N is the rated output of the pump, that is the number of cubic inches of air per revolution the pump supplies at atmospheric pressure

D is the maximum depth in feet to which the driver will descend

E is the percent efficiency of the compressor.

$R \times 0.0303$ equals C, the constant of the pump. The equation can be stated more simply:

$$X = \frac{(DC + R)}{E}$$

For example, a compressor delivers 450 cubic inches of air per stroke. It is to be used to supply a diver working in 66 feet of water. At that depth, it is 80 percent efficient. How many rpm should the pump be run to furnish the minimum air supply, 1.5 cubic feet per minute?

$D = 66$ feet

$N = 405$ cubic inches per stroke

$R = \frac{2{,}592}{405} = 6.4$ revolutions per minute

$C = 0.0303 \times 6.4 = 0.19392$ or 0.194, constant of pump

$E = 0.80$

$$X = \frac{0.194 \times 66 + 6.4}{0.8}$$

$X =$ 24 rpm required to supply 1.5 cubic feet of air per minute to a diver working at 66 feet

18. AIR FLASKS AND OTHER CONTAINERS. a. General. (1) When diving operations at depths greater than 120 feet are conducted from a small boat and air flasks are used, a fully equipped relief diving boat must be kept ready for emergency. No more than two divers at a time are permitted to work from a single boat.

(2) Three or more flasks are connected, with stop valve in the line so the flasks can be changed when necessary. In addition, a flask is always held in reserve for use in emergency.

(3) Pressure in the working flask must exceed the pressure at the bottom by 220 pounds per square inch. Bottom pressure is found by multiplying the depth in feet by 0.445, the pressure per square inch exerted by 1 foot of sea water. As soon as flask pressure approaches the safety margin, divers must be brought up, unless another air supply can be connected immediately to the diving manifold.

b. Precautions in use. When air flasks are used in diving operations, the following precautions must be taken:

(1) Keep stop valve on flask open while diver wears his helmet.

(2) Take diver's air supply from testing tank.

(3) Maintain pressure in testing tank at level set by officer in charge.

(4) Arrange piping so if one valve fails, high-pressure air can be controlled by a duplicate valve.

(5) Do not allow temperature of air supplied to diver to rise so high as to cause him discomfort.

(6) Install high-pressure gauge in flask and low-pressure gauge in line, so tenders can observe pressure at all times.

(7) Use only high-pressure piping with a high-pressure system.

(8) Keep pressure in testing tank 30 to 50 pounds more than bottom pressure.

c. Capacity. (1) The amount of air that can be obtained from an air flask is calculated from the formula:

$$X = 0.068\, C\, P - (234.7 + 0.445\, D)$$

Where: 0.068 is the percent of a cubic foot of air that must be added to raise the pressure 1 pound per square inch

C is the volume of the flask in cubic feet

P is the pressure in the flask in pounds per square inch

234.7 is the safe margin of 220 pounds pressure per square inch, plus 14.7 pounds per square inch needed for charging testing lines and helmet

0.445 is the pressure per square inch exerted by 1 foot of sea water

D is the maximum depth, in feet, to which the diver will descend

(2) For example, a flask with a volume of 20 cubic feet is under a pressure of 2,000 pounds per square inch. The diver is working at 100 feet. How much air per minute can be supplied to the diver?

$$X = 0.068 \times 20 \times 2{,}000 - (234.7 + 0.445 \times 100)$$
$$X = 0.136 \times 2{,}000 - 279.2$$
$$X = 234.0288 \text{ cubic feet of air}$$

(3) The length of time the diver can stay down can be found by dividing the capacity formula by $0.13635\, D + 4.5$, the formula for the cubic feet of air per minute required by a diver at a given depth. Using the same example as above:

$$S = 0.13635 \times 100 + 4.5$$
$$S = 13.635 + 4.5$$
$$S = 18.135 \text{ cubic feet of air per minute}$$
$$\text{Diving time} = \frac{X}{S} = \frac{2340.2880}{18.135} = 129.04$$

The diver can stay down 129 minutes.

19. EXPEDIENTS. Any other methods for safely supplying air to a diver can be used as expedients. Some approved methods are:

a. Hand pumps, bycycle type.
b. Vehicle airbrake compressor.
c. Inflated truck tire, for skin diving only.
d. Any container that can hold the required volume and pressure of air.
e. Wind tunnel hooked to a storage tank with a gauge.

20. DEHYDRATION OF AIR. a. Definitions. (1) *Dehydration.* Process of removing moisture.

(2) *Dew point.* Temperature at which dew begins to form; varies with humidity.

(3) *Humidity.* Moisure held suspended in air; varies with temperature.

(4) *Absolute humidity.* Amount of moisture in air, expressed in grams per cubic foot of air.

(5) *Relative humidity.* Ratio of moisture actually present as compared with greatest amount of air could hold at that temperature.

b. Methods of dehydration. Dehydration, an important phase of air supply, prevents moisture freezing in the diver's lines and cutting off his air. When air is compressed its humidity reaches 100 percent. The moisture content can be reduced in two ways: by cooling and by expansion. High-pressure air-compressor systems includes a cooling system and tanks with reduction valves for decreasing the pressure and allowing the air to expand.

c. Operation. (1) The air temperature is lowered by passing it through coolers through which sea water is circulated. The amount of dehydration by cooling depends on the temperature of the sea water. The coolers must be blown out frequently to remove accumulated water and slush ice. The frequency depends on the relative humidity of the air before compression. When relative humidity is 50 to 70 percent the coolers are blown every 15 to 20 minutes. If it is 70 to 80 percent they are blown every 15 minutes, and when humidity is above 80 percent they are blown every 10 minutes.

(2) The expansion process is best explained by an example. Assume that the initial temperature has been lowered to 30° F. in the coolers. The gauge pressure from the compressor is 150 pounds per square inch; the absolute pressure, then, is 164.7 pounds per square inch.

(*a*) Set the reducing valve to gauge pressure of 100 pounds per square inch, 114.7 pounds absolute pressure. Pressure is decreased from 164.7 to 114.7, a reduction to 70 percent of initial pressure.

(*b*) Refer to the "Dew point temperature curve" (fig. 39). Run a horizontal line from 30° on the vertical scale to the 70 percent pressure curve.

(*c*) Drop a perpendicular line from the 70 percent pressure curve to the base line. The weight of water vapor can be read directly from the base line. In the example used, it is found to be 1.36 grains.

(3) The air is expanded further at the diver's control valve. If humidity is lowered properly at the main reducing valve, no moisture will collect at the diver's control valve.

(4) If the air is too dry, it injures the lungs. Moisture content should therefore be lowered only enough to keep water from freezing in the diver's lines.

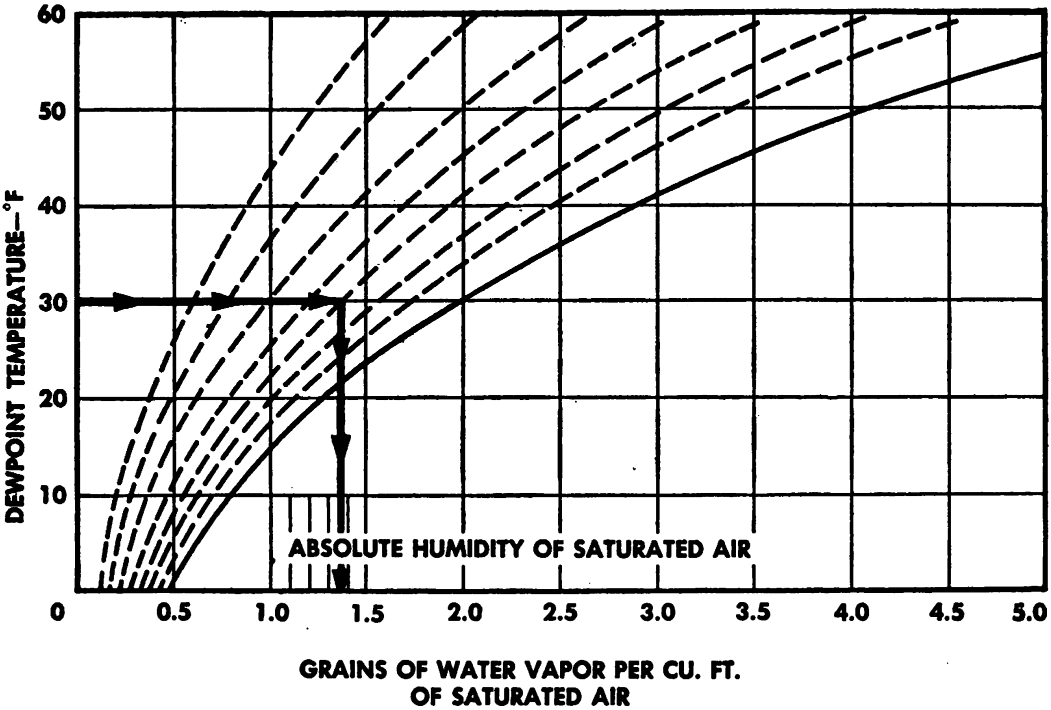


Figure 39. Dew point temperature curve.

SECTION V

DRESSING, TENDING, AND MOORING

21. DRESSING AND TENDING. a. Inspection of diving dress. (1) Before the diver is dressed the dress itself is checked to see that it is in good condition. The man assigned to this duty checks the nonreturn valve by inserting it in the low-pressure air line. He then holds the end in water and looks for bubbles. If no bubbles appear the valve is working properly. He examines the exhaust valve for cleanliness and proper tension. He checks to see that it seats tightly and goes over it for any defects. Next he looks at each sight plate to determine that the lenses are not cracked and are firmly in place and examines the fit of the faceplate. He moves the spit-cock back and forth to find out whether it is sufficiently stiff so it will not accidentally open. He checks the helmet locking lever, making sure that the lock fits snugly in the lug and that the safety key is held properly by the cotter key.

(2) He now inspects the breastplate studs for proper fit. Then he tries out the wing nuts to see if they turn freely on the studs and notes whether the numbers engraved on the breastplate check with the numbers on the breastplate clamps and that the clamps themselves fit properly. He tests the signal halyards and finally he inspects the air-control valve to see that it works with enough stiffness so it will not turn by accident.

b. Dressing the diver. The dress is now ready to put on. To get the diver in it requires two tenders, men who must know each essential step. They work as a team so no time is lost. These tenders are responsible for the diver's safety, for if the diver is not dressed properly he will not be able to perform his assigned duty. The diver also must know whether every step has been correctly done.

(1) First, the diver has prepared himself to be dressed by putting on ordinary uniform trousers and shirt to prevent chafing of his skin. If he is to dive in cold water he puts on thick woolen underwear and heavy diving socks. (See fig. 40.)

The tenders assist the diver whenever possible in pulling on the dress. (See fig. 41 and refer to fig. 1.)

(2) If the dress has cuffs the diver dips his hands in soapsuds before placing his arms and hands in the sleeves so his hands will slide into the cuffs.

(3) If the diver is going to do heavy work on the bottom, chafing pants made of heavy canvas with reinforced knee pads are put on over the legs of the diving dress. (See fig. 42.)

(4) The diver now holds the crotch of the dress up as far as possible while each tender laces one of the legs. (Refer to fig. 2.) Under no circumstances should lacing be omitted since it is an important factor in making the diver stable by preventing the legs of the dress from inflating. Each tender then puts on a shoe making sure the buckles are on the outside. The shoes are laced tightly and also are buckled to give double protection. The loss of a shoe while the diver is on the bottom would be serious for it would shift the center of the diver's buoyancy. (See fig. 43.)

(5) One tender now places the breastplate cushion on the diver's shoulders and pulls the bib up over it. The other tender meanwhile has picked up the breastplate. Once the cushion is in place he slips the breastplate over the diver's head. (See fig. 44.)

Figure 40. Diver in heavy woolen underwear and diving socks.

Figure 41. Tenders assisting diver in putting on diving dress.

Figure 42. Tenders pulling chafing pants on over the legs of the diving dress to protect the dress.

Figure 43. Tenders putting on diver's shoes.

Figure 44. Tender slipping breast-plate over diver's head.

Figure 45. Tenders putting rubber collar over breastplate.

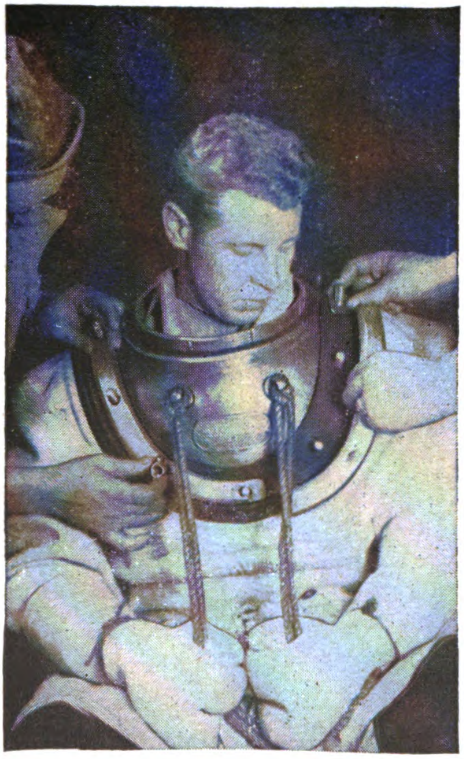


Figure 46. Tenders putting on breast-plate clamps.

Figure 47. Tightening wing nuts on breastplate studs.

(6) The rubber collar on the dress is pulled over it from the front and the holes in the collar are slipped over the studs, each tender working one side. (See fig. 45.)

(7) To clear the breastplate for putting on the clamps the halyard ends are held by the diver. The shims then are placed over the lugs at the breastplate clamp joints. These shims help make a more effective seal and prevent the breastplate clamps from tearing the collar.

(8) The breastplate clamps are put in place attention being paid to the marking "front." (See fig. 46.) The clamps then are tightened by the wing nuts. The wing nuts are tightened by the key wrench, the nuts on the bottom being tightened first and the top ones last. (See fig. 47.) This insures a tight fit and keeps the collar from wrinkling.

(9) The flanged wing nuts for the breastplate clamp joints now are tightened, the one in front first, next the back, then the two sides. One tender tests all nuts with a wrench and removes the nut from the stud which holds the air-control valve link so the stud will be free to receive the air-control valve.

(10) The tenders now slip the jockstrap on to the weighted belt to which the diver's knife already has been attached. They place the belt against the diver's abdomen. Each tender lays a shoulder strap over the diver's shoulder and adjusts the strap so it passes outside the top stud on each shoulder, the straps crossing in front of the breastplate and again in the rear above the

Figure 48. Adjusting straps over diver's shoulder. Note how the tenders are holding the weighted belt.

Figure 49. The jockstrap has been fastened to the weighted belt in the rear. The tender is about to take up the slack on the jockstrap by pulling it between the diver's legs and fastening it in front.

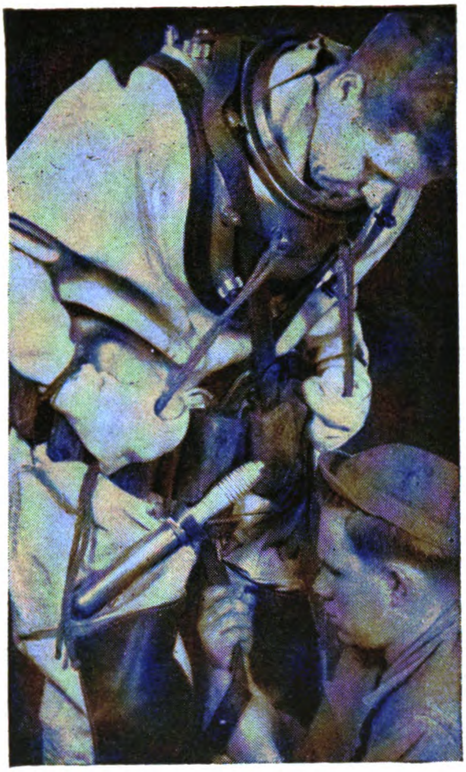


Figure 50. Tender adjusting jock-strap on diver.

Figure 51. Tender slipping helmet over diver's head.

Figure 52. Tenders screwing helmet on breastplate.

Figure 53. Tender lashing air line to padeye on breastplate.

lowest stud in the back. The straps are buckled to the weighted belt in the rear. (See figs. 48 and 49.)

(11) To make the proper adjustment of the jockstrap, the diver stands and bends over forward. (See fig. 50.) This position is assumed so the tender can take up the slack. The diver straightens up and stoops again until straps exercise considerable pressure on his shoulders. The jockstrap must fit snugly to prevent the helmet from being lifted over the diver's head when he is in the water.

(12) The diver is now ready for his helmet. One of the tenders slips the helmet over the diver's head and then both tenders screw it tightly on breastplate making sure the locking lever is in place. (See figs. 51 and 52.)

(13) Next the air line and the telephone life line are lashed to the breastplate. (See figs. 53 and 54.)

(14) Before fastening the air line to the breastplate the wing nut on the stud is removed. The connecting link on the air-control valve is placed on the stud and the wing nut replaced. The air line then is tied with the halyard.

(15) Air now is turned on into the air line and the air-exhaust valve is checked. (See fig. 55.)

(16) The helmet faceplate is closed and the diver is ready to descend. (See fig. 56.)

c. Removing diving dress. When the diver's work is finished and he has ascended, the procedure is reversed. The tenders open the faceplate and seat the diver on the diver's stool. (See fig. 57). They unfasten the tele-

Figure 54. Tender lashing telephone life line to padeye on breastplate.

Figure 55 Adjusting helmet air-exhaust valve.

Figure 56. Fully dressed diver ready to go down.

Figure 57. Tenders seating diver on diver's stool.

phone life line and the air line. They then remove the helmet and take off the jockstrap, belt, and shoes. Next they remove the breastplate clamps and lift the breastplate over the diver's head. Together they unlace the legs and pull the dress off.

d. Tending the diver. (1) *Handling the diver's lines.* (*a*) One of the tenders keeps the slack out of the life line and air hose but avoids pulling on the diver. During the descent, he pays out the line as required but is prepared to held the diver if he stops, pull him up if he so signals, or catch him if he falls. The tender stands so he can see the bubbles when they come to the surface. Both tenders keep in position to pull on the lines instantly and stand so they can brace themselves.

(*b*) If the diver blows up, the tenders take in the slack as quickly as possible. This is necessary because if the dress bursts or if the diver manages to deflate his dress, he will drop at once toward the bottom. In case of blow-up the tenders also close the air-control valve and open the exhaust valve to deflate the dress, then if the diver is all right, send him back down.

(*c*) The tenders keep the life line and air hose free from kinks, turns, chafing, and pinching. To do this properly, the area in which they are operating must be kept clear.

(2) *Signals.* The telephone is important for communicating with the diver, but pulls on the life line and air hose are the primary means of communication. All signals, whether from the diver or tender, are answered with the same signal to indicate that the signal has been received and understood. The tenders transmit signals on the life line and air hose carefully as a heavy jerk may cause the helmet to hit the diver's head, pull him about and throw him off balance. Lack of bubbles coming from the diver or a

sudden large quantity appearing may indicate something is wrong. In either case, the tenders signal the diver to find out what is wrong. If they receive no answer, they give the emergency signal and haul the diver up. Except in an emergency, however, the diver is not hauled up unless he answers the signal to come up. The signals exchanged between the tender and diver are shown in table I.

TABLE I. *Signals used from tender to diver and from diver to tender with life line and air hose lashed together**

Signals from tender to diver

1–Pull.	Are you all right? When diver is going down it means STOP.
2–Pulls.	You have come up too far; go down until we stop you.
3–Pulls.	Stand by to come up.
4–Pulls.	Come up.
2–1–Pulls.	I understand you; or answer the telephone.

Signals from diver to tender

1–Pull.	I am all right.
2–Pulls.	Lower; or give me slack.
3–Pulls.	Take up my slack.
4–Pulls.	Haul me up.
2–1–Pulls.	I understand; or answer the telephone.
5–Pulls.	Send me a line.

Searching signals (from tender to diver)

1–Pull.	Stop and search where you are.
2–Pulls.	So straight ahead.
3–Pulls.	Go to your right.
4–Pulls.	Go to your left.

Air signals (from diver to tender)

3–2–Pulls.	More air.
4–3–Pulls.	Less air.

Emergency signals

2–2–2–Pulls.	I am fouled and need the assistance of another diver.
3–3–3–Pulls.	I am fouled but can clear myself.
4–4–4–Pulls.	Haul me up.

* **Note.** All signals between tenders and divers are answered as they are received. Slack must be taken up in the lines before signals are given. Signals are given by a gentle, distinct pull. Special signals in addition to the above may be used to take care of requirements of special operations.

(3) *Decompression.* (*a*) The tenders always give the diver the decompression required by the standard decompression table. See table II. If the diver has been doing heavy work or if he has been working under adverse conditions, the tenders lengthen the time of decompression. Also if the diver has been under pressure before on the same day, his decompression is based on the total time he spent under pressure.

(*b*) Before the diver ascends, the tenders send down a decompression stage shackled to the descending line so it can run up and down the line. The stage is sent down to the first decompression stop so the diver may sit or stand on it while being decompressed. The tenders watch the life line and air hose carefully, keeping in the slack, to catch the diver if he should lose his hold or fall.

(*c*) When the diver is hoisted out of the water on a decompression stage, none of his equipment is removed until after he steps off the stage. The tenders assist him to the diver's dressing stool, one of them holding firmly to the life line and air hose to prevent the diver from falling. (See fig. 57.)

(*d*) If it is necessary to decompress the diver in a recompression chamber, the tenders remove only the helmet, belt, and shoes before taking the diver into the chamber.

(4) *Emergency ascents.* (*a*) In case of accident or emergency it may be necessary for the tenders to bring the diver to the surface as rapidly as possible despite the possibility of compressed air illness. Under these conditions the speed of the ascent depends on—

1. Nature of the accident or emergency.
2. How long and at what depth the diver has been working.
3. Whether there is a recompression chamber handy and ready for instant use.

(*b*) When a diver fails to answer his telephone or signals, the tenders start him toward the surface immediately. He is stopped at the first stage of decompression and the tenders attempt to communicate with him. If they receive no answer they haul him to the surface at the rate of ascent ordered by the officer or diver in charge. If a recompression chamber is close by and ready for immediate use, or there is reason to believe the diver can be sent down again at once, the tenders are instructed to haul the diver up at a fairly rapid rate of ascent for the remaining distance.

(*c*) In hauling the diver to the surface, the tenders must not bring him up too rapidly as overinflation of the diver's dress due to expanding air may cause him to be blown up. If the diver is conscious, he regulates the inflation of his dress to keep his negative buoyancy and the tenders keep him ascending slowly to the decompression stage. If the diver is helpless he is brought to the surface and decompressed in the recompression chamber.

(5) *Observation of air bubbles.* The tenders watch constantly the air bubbles rising to the surface from the diver's helmet. If the bubbles disappear for over one minute, the tenders ask the diver if he is all right. If the mass of bubbles appearing on the surface is moving around, the diver is not in trouble. However, if the bubbles continually remain in one spot and if there is no movement on the life line, the tenders signal the diver to determine his condition. When divers are using compressed air tools, the tenders know whether the tools are operating by feeling the air lines extending to the tools. If the tool is being used, the tender can feel the pressure variation within the hose. The operation of an arc torch is detected by observing the ammeter; if the diver is using a gas torch, the tender can tell if it is being used by looking at the gauges on the flasks.

22. MOORING. a. General. Safe diving operations from a vessel depend upon the security of the vessel's moorings. Adequate gear must be carried to insure that the vessel can be moored properly and this gear must be inspected carefully before being used. Any shifting of the moorings or veering of the vessel would endanger the diver. Diving lines must have sufficient slack to guard against this contingency. If sudden squalls, heavy seas, or strong currents threaten the security of the moorings, the divers are brought up immediately.

b. Methods of mooring. The methods of mooring depend upon the conditions under which the diving operations are being undertaken. Under normal conditions, the easiest method of mooring is to stand over the spot where the diving is to be done, let go a stern anchor with plenty of line, go ahead past the diving spot and let go a bow anchor. Next drop back, taking in the slack of the stern anchor. If the wind is strong, head into it as the wind probably will have more effect on the boat than the current. Of course, mooring with a wind or a strong current across the boat puts a heavy strain on the anchors. Use the heaviest anchors available that the boat's gear can handle. If heavy anchors are not available, two anchors are used on each mooring line, leaving a few fathoms of line between anchors. An additional mooring on the bow or beam may be necessary to hold the boat from yawing with the wind or current.

23. DIVING LAUNCH. a. When a launch is used for diving operations, sufficient men must be detailed to man the launch, operate the air supply, and tend the divers. Even if only one diver is to go down, there must be another diver aboard with a complete diving outfit for him also. All diving gear is inspected thoroughly before putting it aboard and the man in charge of the operation checks to see that everything required for the job is on hand. His check list should include—

(1) Complete diving outfits for at least two divers.
(2) Extra air hose and fittings.

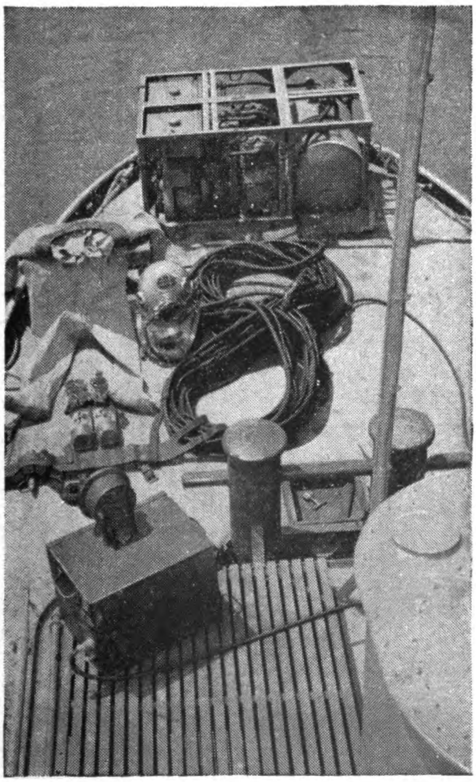


Figure 58. Diving gear on deck of motor launch ready for use. (Note how air compressor is lashed to deck.)

Figure 59. Diver going down ladder assisted by tender.

(3) Spare rubber wrist rings.
(4) Descending and distance lines.
(5) Diving ladder and decompression stage.
(6) Diving amplifier equipment.

b. In addition to the diving gear there must be a red diving flag, lead line, extra anchors for bow and stern, signaling flags, first-aid kit, bucket of soapy water if dress without gloves is used, drinking water, and whatever special gear may be required for the particular job on hand. Figure 58 shows diving gear on deck of motor launch ready for use.

SECTION VI
THE DESCENT

24. GENERAL. a. Instructions to diver. Before going down, the diver should understand what he is to do and the conditions under which he is to work. If possible, illustrate his work on a drawing or sketch.

b. Testing diving gear. As he is dressed, the diver checks each operation to make sure that he is dressed properly. As soon as the helmet is on, the diver tests his telephone by talking to the telephone tender and having him reply. When the air-controlled valve is in place he opens it to test his air supply. He makes sure that the exhaust valve is open three full turns. This normally gives the diver proper ventilation at most diving depths.

25. DESCENT. a. By descending line. (1) When the diver indicates that he is ready, the faceplate is closed tightly and the tenders assist him to the descending ladder. While going down the ladder, one of the tenders holds the life and air lines firmly to prevent the diver from slipping or falling. (See fig. 59.)

(2) When the diver is in the water but before he has submerged, he adjusts his air-control valve if necessary. (See fig. 60.)

(3) If the diver requires tools to do his job on the bottom, they are put in the diver's tool bag which is handed to him just before he submerges.

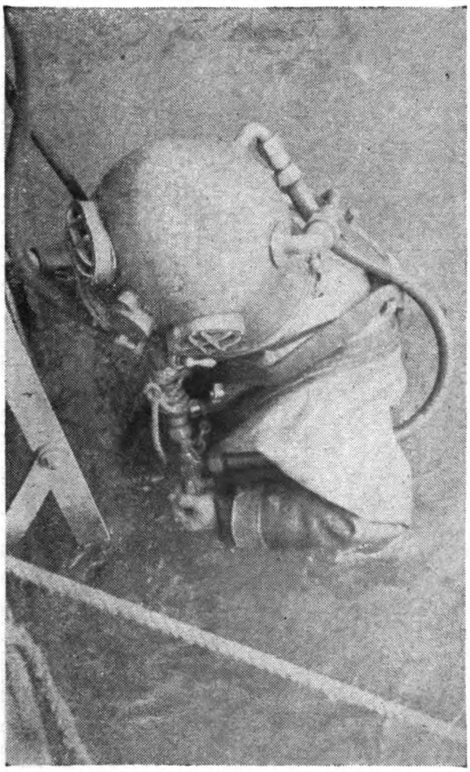


Figure 60. Diver adjusting air-control valve before going down. (Note descending line in foreground.)

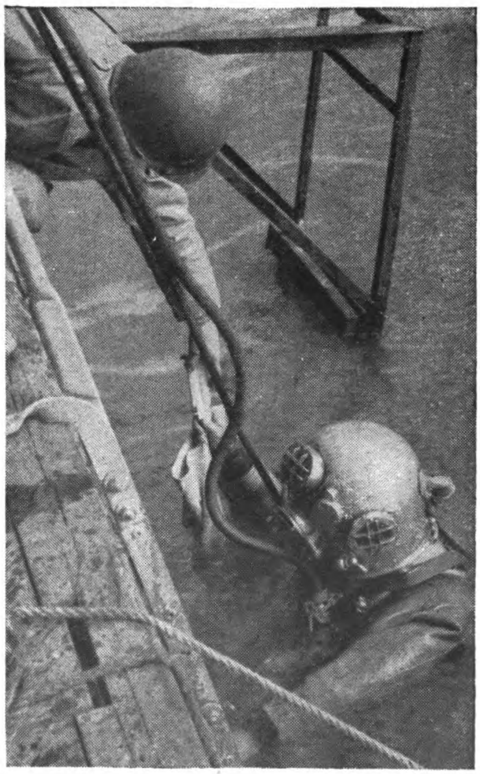


Figure 61. Diver receiving tool bag from tender just before submerging.

(See fig. 61.) Compressed air and heavier tools are sent down on separate lines. The diver slips the tool bag over his right arm.

(4) Now the diver gets his signal to descend—two taps on his helmet; he grasps his descending line and starts to go down. (See fig. 62.)

b. By decompression stage. (1) If the diver is to make his descent on the decompression stage, the tenders assist him to the stage one of them holding firmly to the air and life lines to prevent the diver from falling. (See fig. 63.)

(2) The stage now is swung clear of the float and the diver is ready to begin his descent. (See fig. 64.)

(3) The diver keeps a firm grasp on the stage as it is lowered. (See fig. 65.)

(4) The stage is halted just before the diver is completely submerged so the diver can adjust his air-control valve if necessary before going down. (See fig. 66.)

c. Precautions in the descent. The diver keeps his body between the flow of the current and his descending line so the current will not pull him away from the line. *The diver hooks his legs around the descending line and holds onto it with his right hand, making necessary adjustments of his air-control valve with his left hand.* He goes down at a speed which permits him to equalize pressures and "pop his ears" *but he must be able to check his rate of descent when necessary.* The following factors limit the rapidity of the diver's descent:

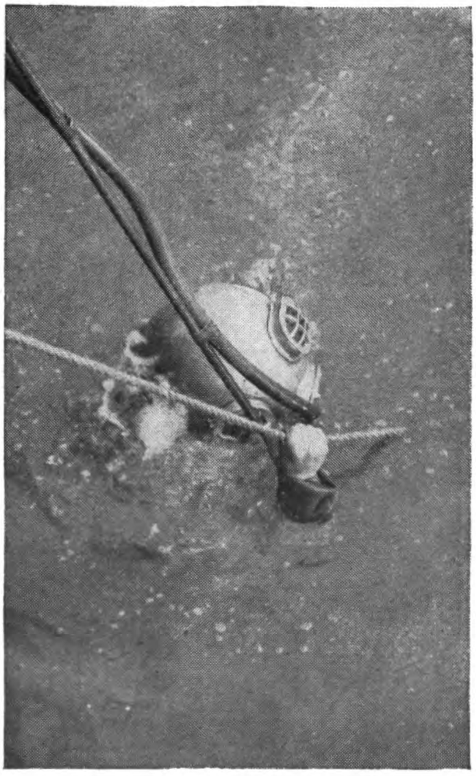


Figure 62. Diver going down on descending line.

Figure 63. Diver standing on stage ready to be swung clear of diving float.

Figure 64. The stage is swung clear and is about to be lowered.

Figure 65. *Diver on stage entering the water.*

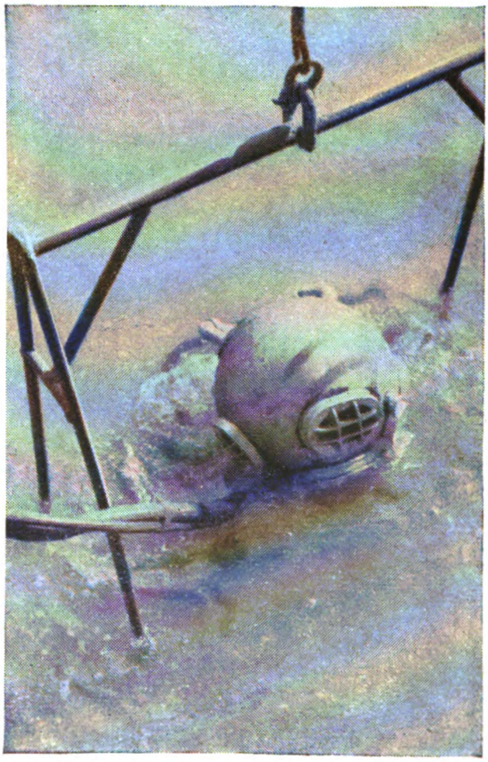


Figure 66. Diver halted so he can make final adjustment of air-control valve.

(1) Possibility of squeeze.
(2) Inability to equalize pressure on both sides of ear drums.
(3) Pain in sinus passages.
(4) Tendency toward dizziness.
(5) Necessity of approaching bottom cautiously, as in case of entering a wreck.
(6) Strength of current.

d. Ear pains. Pains in the ears during descent are a warning that the ear drums may be threatened. The diver should stop, try to "pop his ears" or ascend a few feet before going down farther. If the dive is being made in deep water and the diver has trouble with his ears in getting down to 30 feet, he should return to the surface and not attempt the dive.

e. Air supply. As the diver descends, the volume of his air supply should be in proportion to the greater pressures at increasing depths. Insufficient air supply during descent may force the diver to stop because of "squeeze." The diver adjusts his air supply so he breathes easily and comfortably without endangering his stability. *He spends a minute or two at his descending line to permit his body to adjust itself to the new pressure level.*

SECTION VII
WORKING ON THE BOTTOM

26. GENERAL. The following general suggestions help the diver to work efficiently and safely.

a. Control of air. The diver must make constant valve adjustments as he works so he can breathe comfortably, no matter what position he is in.

(1) Never close the air-control valve completely unless the air hose has ruptured. Make only extremely small changes in the valve setting; opening it only halfway lets in more air than can escape by the spitcock and air-regulating exhaust valve and "blow-up" may occur.

(2) Set the air-regulating exhaust valve at the desired number of turns before the dive.

(3) Use the helmet air-regulating exhaust valve chin button to release air pressure quickly when desiring to stoop or crawl on the bottom. Grasp the chin button with the lips if more pressure or rapid inflation is desired. These methods save resetting the air-control valve and air-regulating exhaust valve and are particularly useful when both hands are occupied and a change in pressure is desired.

(4) The helmet spit cock can also be used to relieve excess pressure. Remember that the helmet air-regulating valve and the safety valve in the helmet gooseneck seat themselves if the air supply is interrupted, while an open spit cock must be closed by hand.

b. Meeting emergencies. Never become frightened or excited in case of emergency, and do not overexert in trying to get free. Slow and methodical work is best. A diver must have confidence in himself and in his tenders. *At the slightest sign of distress he should stop, rest, and notify the surface.*

(1) If the air supply is cut off, there will be enough air left in the helmet for 6 to 9 minutes breathing. This is enough time for emergency air-supply measures to be instituted.

(2) Lines can become so badly fouled that one man cannot untangle them. Ask the surface to send down a relief diver to replace the air hose and life line. This can be done safely.

(3) In extreme darkness it may be hard to relocate a lost distance line. Signal the tenders. They will haul up on air hose and life line, keeping those lines close to the descending line, until the descending line is reached. As soon as the descending line is located, signal the surface to lower. Pick up the distance line where it meets the descending line and return to the work.

(4) *If a leak develops in the dress, remain in an upright position.* Keep the tear below the level of the helmet. If the face plate should crack, bend over to keep the face plate down and increase the air supply. Air pressure will keep water from leaking in. Report the accident at once.

27. PREPARATIONS. a. Adjusting air supply. *Setting the helmet air-regulating exhaust valve at two and one-half to three turns and adjusting the air-control valve usually gives a diver proper ventilation and inflation.* When he arrives on the bottom, the diver first adjusts his air supply to the new pressure and regulates his air to lift helmet and breastplate off his body enough to make him comfortable without destroying his negative buoyancy.

That done, he observes his general condition; he should feel comfortable and at ease while standing in a restful position. If his helmet windows are fogging over and he is dizzy, unduly warm and perspiring unnaturally, or breathing rapidly, there is too much carbon dioxide in his helmet. This is easily remedied by increasing the amount of air circulating through the helmet without increasing inflation of the diving dress. Adjust both valves, at the same time operating the air-control valve with the left hand and the exhaust valve with the right. When the air supply is increased, the exhaust is simultaneously increased, and vice-versa, until the desired settings are obtained.

b. Checking lines. While still at the descending line, the diver clears his distance line and makes certain that his air and life lines have not fouled the descending line.

c. Orienting. The diver's last step before starting work is to orient himself.

(1) Before descending, the diver should note the direction of his work with reference to the sun. Then when he reaches the bottom, he can guide himself to his work by observing the direction of the brightest light. For example, if on the surface he saw the sun in the left helmet window as he faced his work, he will face his work on the bottom when the greatest amount of light shines through the left helmet window. Orientation is easy when the light is good. If it is poor, the diver can determine the direction of brightest light closely by turning slowly from side to side. If he turns too far to the right of the light the right window will appear darker than the left; if he turns too far to the left, the left window will appear darker.

(2) When there is no light, the diver can use the current as a guide. However, the current on the bottom does not always flow in the same direction as it does on the surface. Therefore, if the diver starts off in the wrong direction, his tenders redirect him. When a tender directs him to the left, the diver first faces the direction in which his lines are running and then goes to his left.

28. SENDING DOWN TOOLS. a. Hand Tools. The tools that a diver carries with him to the bottom are fitted with lanyards and slipped over his right forearm or are placed in the tool bag held on his right forearm. About 3 feet of marline is used to secure all small tools, bolts, nuts, and small fittings to the eyelets of the tool bag.

b. Power tools. When power tools are used they precede the diver to the bottom. They are attached by six-thread manila to a sliding shackle on the descending line and are lowered by the tool's air hose. An electric or a gas torch is sent down in the same manner, the electric torch ground wire or the gas torch hose being used as the lowering line. Tools with no attachment that can be used as a lowering line are lowered with a 14- to 21-thread manila attached to the sliding shackle by an eye splice. The tools are fastened to the shackle with marline. Care must be taken to keep the lowering line from fouling the descending line.

c. Lowering lines. When a diver is working with several lines, each of them should be of different size or material or be clearly marked with small, colored rags. The diver can then tell what each line is for and will not cut a line which he will later need. A new line will shrink and twist under-

water and therefore a weight is tied to one end and the line left in water for some time before the line is used.

29. MOVING UNDER WATER. a. General. From the time a diver leaves the descending line until he returns for the ascent, he moves slowly and cautiously. He keeps constant watch on all sides, taking partictular notice of obstructions. When he passes a standing object, he notes the side on which he passes; on his return, he makes sure he passes on the same side so his lines will not foul. Normally, he passes over, not under obstructions, to avoid fouling his lines. For the same reason, he never passes under the boat from which he is diving. If it becomes necessary for him to work on the other side of the boat, he notifies the surface and has his lines shifted to that side. He carries one turn of air hose and telephone cable on his arm to take up the shock of a sudden pull on his lines that would otherwise pull him off balance. He allows hose and cable to touch bottom behind him, but does not let it pile up or kink. As he moves, he makes the necessary adjustments to his air supply.

b. In swift currents. A diver can move easily in slack water but as current increases it becomes increasingly difficult to advance. By bending over, the diver reduces the area of his body exposed to the sweep of the current. He can move forward with much less difficulty in a stooping or crawling position. However, since his valves were adjusted for an erect position, air accumulates in his dress and tends to make him too buoyant when he is bent over. He can relieve excess air by manipulating his chin button or spit cock.

c. On rocky bottom. When moving on a rocky bottom, a diver must be careful not to catch his arm, leg, or lines in a crevice. On sharp rocks or coral, he wears gloves to protect his hands and chafing pants to protect the legs of his dress. Tenders must be particularly alert to take in slack to prevent lines fouling. There is an increased chance that the diver may slip on a rock and fall into deeper water. If he does slip, he immediately signals his tender to hold on; at the same time, he adjusts his air supply to increase his positive buoyancy.

d. On muddy bottom. The diver operates with particular caution on a muddy bottom. If he flounders around, he stirs up a cloud of silt which will prevent him from seeing anything. He keeps down current of his work, so the mud stirred up by the current will not interfere with his vision. On especially soft bottoms, he keeps himself as light as possible. If he should sink, he can free himself by increasing his positive buoyancy. He should do this carefully and gradually so he does not suffer a "blow-up" when he does break loose.

e. Around moorings. Movement around moorings requires particular care because of the danger of fouling. The diver keeps close track of the movements he makes and always uses a distance line so he can retrace his steps. Old moorings are often covered with sharp barnacles, so he takes care not to cut his dress. A diver should not descend on a chain or wire unless it is absolutely necessary. Moorings, chains, or wires must not be veered, lifted, or moved until it is known that the diver is clear.

f. Entering wrecks. A diver always proceeds feet first in entering a wreck or going through a restricted opening. He must never try to force his shoulders and breastplate through the hole.

30. SEARCHING FOR LOST ARTICLES. a. Stationary diving boat. A diver searches for lost articles by exploring the bottom in a series of concentric circles.

(1) To accomplish this, he moves down current of the descending line, remaining close enough so he can examine all ground between himself and the descending line. He marks his starting point and then, keeping the distance line taut, he moves in a circle around the descending line. When he arrives at his starting point, he moves out a little farther from the descending line, and this time circles in the opposite direction to keep from wrapping his air hose and life line around the descending line. Generally, it is better to crawl along the bottom unless the water is exceptionally clear and walking gives a better field of vision.

(2) When the tide or current is strong, the diver may be unable to make a complete circle. In that case he works back and forth across the current as far as he can go, searching in rough semicircles.

(3) If the entire length of the distance line has been covered and the object still not found, the next step is to move the diving boat.

b. Moving the boat. There are two methods of widening the searched area by moving the diving boat.

(1) The diver completes the search of an area and reports his failure to the diving boat. The boat marks its position with a buoy and then moves a short distance to an adjoining location. The diver repeats the underwater exploration and if still unsuccessful reports this fact to the surface. Again the boat marks its position and moves to a new one. The buoys are left in the water to mark the boundaries of the searched area, and the process is continued until the object is found.

(2) In the second method, two buoys are set out a long distance apart and a surface line is stretched between them. The diving boat, with diver on the bottom, is ferried along, the surface line being taken over bow and payed out over stern rollers. The boat is moved by pulling on the line and stopped by holding onto it, according to the diver's signals. This method has the advantage of being faster, of carrying out the search more exactly, and giving better control of the movement and speed of the boat.

c. Marking the object. When the object of the search is located, the diver fastens his distance line to it. On subsequent dives it can be found quickly by following the distance line from descending line to object.

31. REPAIRING A SHIP'S BOTTOM. a. Preparation. When a diver is repairing the hull of a floating ship, he is suspended in water and is in danger of falling. To prevent this, a stage should be rigged to give him some substantial support. In addition, his attendants must keep a good hold on his lines. Under no circumstances should the diver try to support himself by using an overhead handhold; he may lose the air from his dress through his cuffs and become so negatively buoyant that he will fall and suffer a serious "squeeze." Rigging lines and stages give the diver stability, make it easier for him to reach the work and greatly increase the amount of work he can do. The following rigs are easily contrived.

(1) Lash two or more Jacob's ladders side by side and weight the lower ends. Hang the ladders from spars projecting about 2 feet over the ship's side. Haul the ladders under the bottom with hogging lines. The divers work between the ladders and the ship and are thus protected from falling.

(2) When the work is to be done on the keel of a vessel which has a flat

bottom, a variation of the above can be used. Lace a net between two Jacob's ladders and separate the ladders with spars lashed in place to stretch the net. Pass the rig under the keel by means of hogging and tricing lines. The diver can lie in the net and work with comparative ease.

(3) Another type stage can be rigged with spars and ropes. Take two long ropes and at their centers clove-hitch two 20- to 25-foot spars about 4 feet apart. A third spar about 16 feet long is hung horizontally about 3 feet below one of the long spars, and weights are slung from the bottom spar to overcome its buoyancy. Wooden crosses about 3½ feet long are fastened to each end of the other long spar to keep it from being pulled too close to the ship. One end of the long ropes is used as a tricing line to hold the weight of the stage; the other end is used as a hogging line to hold the stage in and bind it to the ship's side. Two divers can work from this stage; it can be raised and lowered with the divers on it.

b. Patching. Collision mats, patent leak stoppers, mattresses, canvas, swabs, cotton waste, calking, wedges, and a number of other expedients have all been used successfully to make emergency repairs to a damaged ship. The actual procedure varies with each job, and methods must be devised to meet the emergency of the particular case.

(1) Small leaks, such as leaky rivets, plate seams, and cracks in shell plating, are repaired with standard pneumatic calking tools if time permits. A quick but temporary method is to use leak-stopping material like sawdust, shavings, straw, or unravelled oakum. The diver takes this material down and releases it at some point below the leak. The material, being buoyant, rises and is caught by the current of water flowing into the ship through the leak. It lodges in the crack and swells, stopping the leak. When the exact location of the damage is known, work the following mixture directly into the leak: 65 percent lamb tallow, 25 percent powdered charcoal, and 10 percent Portland cement. This provides an effective seal.

(2) Small holes, such as empty rivet holes and ruptured plate seams, can be patched with plugs and wedges of white pine or a similar soft wood. If the holes are so situated that plugs might become dislodged, seal rivet holes with bolts, using washers on both sides of the hole. When wedges are used, they should be supplemented with calking material such as tallow or oakum.

(3) Moderate-sized holes too big for a plug and too small to require a standard patch can be closed temporarily with blankets, mattresses, pillows, or collision mats. Later, this temporary patch is replaced by one of concrete.

(4) Large patches are applied as follows: the diver goes down and cuts away all fractured or torn plate so the patch can be fastened to solid plating. The size of the hole is now measured and reported to the surface. A frame is constructed to these dimensions and lowered to the diver, who secures it in place temporarily and then uses battens to build the frame up to match the curvature of the hull. This template is raised to the surface and built up to match the curvature as indicated by the battens. The framework is then covered by tongue-and-groove planking or ordinary planking calked with oakum or covered with canvas. The inside bearing surface is covered with a 4-inch thick cow-hair felt gasket. The patch is then weighted and drawn into place with hogging lines or a block and tackle. If it is impossible to get to the region of the patch from the inside to secure the bolts, it can be left unbolted temporarily. The outside pressure of the water will seat it and hold it in place until it can be bolted.

c. Clearing a fouled propeller. Propellers fouled by rope or wire hawsers are difficult to clear.

(1) The diver first attempts to clear one end of the fouled hawser. If he can do so, surface tackle is used to try to pull the fouling loose. The propeller can be turned with the jacking engine to help loosen the hawser; care must be taken to see that the diver has moved out of the way before the propeller is turned.

(2) If this method is unsuccessful, the fouling must be cut loose. Rope hawsers can be cut with a knife, hacksaw, chisel, and similar tools. Wire hawsers are cut in one of three ways. The fastest method is to use a power-driven cable cutter, if the hawser does not have a diameter of more than 1 inch. They can also be cut by burning with an underwater gas or electric torch. The slowest method is cutting with a saw or cold chisel.

d. Clearing valves. Valves can usually be cleared from the outside with a wire brush and a pricker to clear the holes. If barnacles have gathered inside the grating, it must be taken off to remove them. The position of the grating should be marked before removal, to facilitate replacing it. When the valve must be removed, the holes must be plugged by one of the methods discussed above. The plug should then be cut off flush with the ship's side, the outside covered with wood, and lined with greased heavy cloth to prevent leakage. If the valve is to be kept out only a short time, this covering requires only temporary fastening as water pressure will hold it in place.

32. RECOVERING ANCHORS. In recovering an anchor, the descending line is dropped alongside the marking buoy. The diver goes down, holding the descending line and the buoy line apart to keep them from fouling.

a. A wire hawser is prepared by fitting a large shackle to the hawser eye, and fixing another shackle a short distance above the first with its crown against the wire. The shackle pins should be fixed by lanyards to prevent their loss. The wire is hooked to the descending line by the upper shackle, and lowered carefully when the diver signals for it.

b. The diver shackles the hawser to the anchor and returns to the surface before any attempt is made to raise the anchor. This same method is used for raising other heavy weights.

c. If the body to be lifted is of convenient shape, a sling can be rigged around it and the lifting hawser shackled to the sling.

33. ASSISTANT DIVERS. Sometimes a diver works with an extremely long life line and air line and it becomes difficult for him to pull them around after him. In other instances, his work takes him around several corners so handling his lines becomes difficult. Assistant divers can be used to advantage in these cases. The assistant helps carry and tend the diver's lines. It should be remembered, however, that the more divers submerged at one time, the greater the possibility of fouling the lines. The comparative advantage and disadvantage of using assistant divers should be weighed in the light of the problems in each job.

34. CLEARING FOULED LINES. a. Without assistance. When lines foul, the diver tries to free himself by slow, methodical efforts. He uses his distance line as a guide and retraces his steps through the tangle. He notifies his tenders that he is fouled and they slowly take up slack in his lines. If

the lines foul in opposite directions, he tells the tender to take up slack in one of them while he traces the other and tries to clear it. Then he repeats the process with the other line. If necessary, the diver cuts the telephone cable or life line and concentrates on clearing the air line. If he cannot clear himself, he reports to the surface and asks for help.

b. With assistance. Whenever a diver is working in a place where there is danger of fouling, a second diver is always in readines to go to his assistance. The relief diver follows the fouled air hose as he descends, so he can find the tangle quickly. If after locating it he cannot free the lines, he prepares to substitute new ones as follows:

(1) He fastens new life line around fouled diver's waist.

(2) He locates nearest free coupling of fouled air hose.

(3) While fouled diver closes his air-regulating exhaust valve and his air-control valve, relief diver uncouples fouled air hose and connects new one.

(4) If an air-control valve is not used, hose coupling to be disconnected must be at or below level of fouled diver's feet.

SECTION VIII

ASCENT AND DECOMPRESSION

35. GENERAL. The most important feature of the ascent is decompression of the diver. It is essential that the diver's return to atmospheric pressure be slow and gradual. Failure to observe this can result in compressed air illness. The most efficient, practical, and safe method is stage decompression. This consists of reducing the pressure on the diver in definite stages. The depth of dive and time on the bottom determine the number of stages and the time and pressure at each. There are two methods of stage decompression: regular and surface decompression.

36. REGULAR DECOMPRESSION. a. Method. In regular decompression, the diver is raised to a predetermnied depth and kept there for a definite time. He is then raised at a rate no faster than 25 feet per minute to a higher level and kept there while his body accommodates itself to the lowered pressure. This process is repeated till he reaches the surface.

b. Decompression table. The time and depths at each stage are taken from the decompression table (table II). The table must be followed exactly. Note that it lists the decompression time required for varying lengths of dives at each depth.

Table II. Decompression table.

Depth	Time under water from surface to beginning of ascent	Stoppage at different depths in minutes									Total time for ascent
		90 ft.	80 ft.	70 ft.	60 ft.	50 ft.	40 ft.	30 ft.	20 ft.	10 ft.	
Feet											*Minutes*
0–36	No limit										0–1
36–42	Up to 3 hrs.										1–1½
	Over 3 hrs.									5	6
42–48	Up to 1 hr.										1½
	1 to 3 hrs.									5	6½
	Over 3 hrs.									10	11½
48–54	Up to ½ hr.										2
	½ to 1½ hrs.									5	7
	1½ to 3 hrs.									10	12
	Over 3 hrs.									20	22
54–60	Up to 20 min.										2
	20 min. to ¾ hr.									5	7
	¾ to 1½ hrs.									10	12
	1½ to 3 hrs.								5	15	22
	Over 3 hrs.								10	20	32
60–66	Up to 15 min.										2
	¼ to ½ hr.									5	7
	½ to 1 hr.								3	10	15
	1 to 2 hrs.								5	15	22
	2 to 3 hrs.								10	20	32
	Over 3 hrs.								10	30	42

Depth	Time under water from surface to beginning of ascent	Stoppage at different depths in minutes 90 ft.	80 ft.	70 ft.	60 ft.	50 ft.	40 ft.	30 ft.	20 ft.	10 ft.	Total time for ascent
Feet											*Minutes*
60–72	Up to 15 min.									2	4
	¼ to ½ hr.								3	5	10
	½ to 1 hr.								5	12	19
	1 to 2 hrs.								10	20	32
	2 to 3 hrs.								10	30	42
	Over 3 hrs.								20	30	52
72–78	Up to 20 min.									5	7
	20 to 45 min.								5	15	22
	¾ to 1½ hrs.								10	20	32
	1½ to 2½ hrs.								20	30	52
	Over 2½ hrs.								30	30	62
78–84	Up to 20 min.									5	7
	20 to 45 min.								5	15	22
	¾ to 1½ hrs.								10	20	32
	1½ to 2 hrs.								15	30	47
	2 to 3 hrs.							5	30	30	67
	Over 3 hrs.							10	30	35	77
84–90	Up to 20 min.								3	5	10
	20 to 40 min.								5	15	22
	40 to 60 min.							3	10	15	30
	1 to 1½ hrs.							5	15	25	47
	1½ to 2½ hrs.							25	30	30	67
	Over 2½ hrs.							20	35	35	92
90–96	Up to 20 min.								3	55	11
	20 to 35 min.								5	15	22
	35 to 55 min.							5	10	15	32
	55 min. to 1½ hrs.							5	15	30	52
	1½ to 2½ hrs.							10	30	35	77
	Over 2½ hrs.							30	30	35	102
96–108	Up to 15 min.								3	5	11
	15 to 30 min.							5	7	10	23
	30 to 40 min.							5	10	15	33
	40 min. to 1 hr.							10	15	20	48
	1 to 2 hrs.						5	15	25	35	83
	Over 2 hrs.						15	30	35	40	122
108–120	Up to 15 min.							2	3	8	15
	15 to 25 min.							5	5	10	23
	25 to 35 min.							5	10	15	33
	35 min to 1 hr.						5	10	15	25	57
	1 to 2 hrs.						10	20	30	35	97
	Over 2 hrs.						30	35	35	40	142

Depth	Time under water from surface to beginning of ascent	Stoppage at different depths in minutes									Total time for ascent
		90 ft.	80 ft.	70 ft.	60 ft.	50 ft.	40 ft.	30 ft.	20 ft.	10 ft.	
Feet											*Minutes*
120–132	Up to 15 min.							2	5	7	17
	15 to 30 min.							3	10	15	33
	30 to 45 min.						5	10	15	20	53
	¾ to 1½ hrs.					5	10	20	30	30	98
	Over 1½ hrs.					15	30	35	40	40	163
132–144	Up to 12 mir.							3	5	5	16
	12 to 25 min.						2	5	10	12	32
	25 to 45 min.					3	5	10	15	25	61
	¾ to 1½ hrs.					10	10	20	30	35	108
	Over 1½ hrs.					30	30	35	40	40	178
144–156	Up to 10 min.							3	5	5	16
	10 to 20 min.					2	3	5	8	18	31
	20 to 35 min.					3	5	10	20	20	61
	35 min to 1 hr.					7	10	15	30	30	95
	Over 1 hr.				20	25	30	35	40	40	193
156–168	Up to 10 min.						2	3	5	5	18
	10 to 16 min.					2	3	5	7	10	30
	16 to 30 min.					3	5	10	15	20	56
	½ to 1 hr.				3	10	10	15	30	30	101
	Over 1 hr.			5	25	25	30	35	40	40	203
168–180	Up to 9 min.						2	3	5	5	18
	9 to 14 min.					2	3	5	7	10	30
	14 to 20 min.					3	3	7	10	15	41
	20 to 30 min.				2	2	3	10	15	25	60
	½ to 1 hr.			3	3	7	10	20	30	35	111
	Over 1 hr.			15	25	30	30	35	40	40	218
180-192	Up to 13 min.					2	3	5	7	10	30
	13 to 20 min.					3	3	7	15	15	46
	20 to 30 min.				3	3	5	10	15	25	64
	½ to 1 hr.			3	5	10	12	20	30	35	118
	Over 1 hr.		5	20	25	30	30	35	40	40	228
192–204	Up to 12 min.				2	2	3	5	7	10	32
	12 to 20 min.				3	3	5	7	10	20	61
	20 to 30 min.			3	3	3	5	10	20	30	67
	½ to 1 hr.		3	3	5	10	15	20	30	35	124
	Over 1 hr.		15	20	25	30	30	35	40	40	238
204–225	Up to 10 min.		2	2	3	5	7	10	10	15	58
225–250	Up to 10 min.	2	2	3	5	7	10	10	15	15	73

37. SURFACE DECOMPRESSION. **a.** It can be seen from the tables that after a protracted deep dive, regular decompression requires a long period of time. Frequently, tide and weather conditions make these long decompres-

sion periods a hardship or even a danger. When the officer or diver in charge believes conditions warrant and if a recompression chamber is aboard, surface decompression is used. However, depth and duration of the dive must be within the limits of table III.

TABLE III.—*Limits of depths and exposure for surface decompression.*

Depth (feet)	Pressure (pounds per square inch)	Exposure (minutes)
100	44.5	85
110	48.95	75
120	53.4	60
130	57.85	55
140	62.3	45
150	66.75	40
170	75.65	30

b. To use surface decompression—

(1) The diver is brought up to the first stop as in regular decompression and kept there for the normal length of time.

(2) He is then brought to the surface *at a maximum rate of 25 feet per minute* and hoisted aboard.

(3) As quickly as possible, his helmet, belt, and shoes are removed and he is placed in the recompression chamber.

(4) The pressure in the chamber is raised to that of the diver's first stop, the decompression time at that stop repeated, and the remainder of the decompression completed in accordance with the decompression table.

38. SAFETY RULES. The following general procedures must be observed:

a. The maximum speed of the diver's ascent at any time is 25 feet per minute.

b. The timekeeper must keep accurate records of the depth and duration of all dives so decompression can be carried through properly. His record includes the time the diver enters the water, the time the descent starts, when he reaches bottom, the start of the ascent, and the depth and duration of each stop during decompression. If there is any question about time, allowance is made in the diver's favor. The timekeeper notifies the diving officer just before it is time to raise the diver to the next stop, so preparations for hoisting can be made and the diver notified.

c. Close communication is maintained with the diver during the ascent, so he can notify the surface at once if he experiences symptoms of compressed air illness or if his lines are fouled. The diver is warned whenever he is to be lifted.

d. If, during the ascent, the diver reports symptoms of illness, he is returned immediately to the first decompression stop and decompression is begun again. This second decompression is based on double the actual time of the dive.

e. When surface decompression is used, the diver must be in the decompression chamber within 2½ minutes of the time he is taken from the water.

f. The decompression tables are adequate for water temperatures usually encountered. In extremely cold water, desaturation of body tissues may take longer.

g. After regular decompression, the diver remains dressed, except for helmet and belt, for at least 20 minutes. If during that time no symptoms of illness are observed, the dress can be removed. The diver remains in the immediate vicinity for at least an hour longer and for the next 11 hours should be within an hour's travel time of decompression facilities. If the dive was extremely deep, the diver should remain aboard under observation for 8 to 10 hours after decompression.

h. If, in an emergency, a man makes more than one dive in a 24-hour period, decompression is based on the following:

(1) Exposure time is considered the sum of the time of the two dives.

(2) The depth is that of the second dive.

39. THE ASCENT. a. Preliminary steps. Shortly before the ascent is to start, the diver is notified.

(1) The diving stage is shackled to the descending line so the diver can find it easily and lowered to the first stop as determined from the decompression table. The attendant takes up the slack in the diver's line.

(2) The diver begins preparations to rise immediately on receiving the warning notice, so he will not exceed his time on the bottom. He disposes of his work, moves to the descending line, and makes certain that nothing will interfere with his ascent. He throws one leg around the descending line in the same manner as in the descent, signals "Coming up," and waits for confirmation from the surface.

b. Coming up. The surface signals the diver "Come up" as soon as preparations are complete.

(1) The diver lightens his weight by inflating his dress and climbs up the descending line to the stage. He keeps his left hand on the control valve and adjusts it as necessary, maintaining a slight negative buoyancy so he will not rise too quickly. He must not climb faster than 25 feet per minute. Attendants are responsible to watch the lines as they take in the slack to see that the diver is not exceeding that speed.

(2) The attendants warn the diver when he is approaching the depth of the stage. Thereafter he rises even more slowly, keeping a careful watch, until he reaches the stage. He seats himself on it and notifies the surface. The decompression process begins.

(3) If a diver feels unable for any reason to climb from the bottom to the stage, he notifies the surface. Attendants haul him to the stage by his lines.

c. At the surface. When the stage reaches the surface, the method by which the diver is brought aboard depends on the equipment available.

(1) If the vessel has hoisting gear, the stage is lifted out of the water, swung clear of the gunwale, and lowered to deck. The diver is helped off, seated, his faceplate opened, and the air-supply valve closed. His helmet is then removed.

(2) When diving operations are conducted from vessels not fitted with hoisting equipment, the stage is hauled up by hand till it reaches a ladder hung from the gunwale. The diver climbs the ladder till his waist is even with the gunwale. He is secured there with his lines, his faceplate opened, and his condition observed. If he shows signs of compressed air illness he is sent down again immediately. (See par. 40.) If he seems all right, the attendants lift him into the boat and remove his helmet.

SECTION IX

DIVING INJURIES AND THEIR TREATMENT

40. COMPRESSED AIR ILLNESS. a. General. Compressed air illness is the most common diving injury. It is caused by inadequate decompression, too sudden reduction of pressure, or too rapid ascent. Illness rarely occurs if the dive has been in water shallower than 45 feet (20 pounds pressure) unless the diver has been working unusually hard or the dive was unusually long. Regardless of precautions taken, illness occurs in about 5 percent of all cases.

b. Cause. When a diver works under pressure, some of the nitrogen in the air is forced into solution in the blood and tissues. If pressure is decreased suddenly, the nitrogen is released from solution in much the same manner as gas in soda water when the bottle is opened. In stage decompression, some nitrogen is discharged from solution at each stage and the body is able to eliminate it. Rapid reduction in pressure permits the body to get rid of only a small portion of the nitrogen. The balance comes out of solution in the form of bubbles which form slowly and may take some time to become large enough to cause distress. The bubbles cause local or general blocking of circulation or pressure on the nervous system.

c. Symptoms. Symptoms usually occur within an hour after the dive, though there have been cases of illness beginning 15 hours later. The depth and duration of the dive and the method and adequacy of decompression affect the degree of illness. Primarily, however, this depends on the amount of gas liberated in the body and where the bubbles lodge.

(1) Formation of bubbles in the small blood vessels of the skin and in surrounding tissue causes itching, burning, and a mottled rash.

(2) Their presence in and around tendons, bone muscles, and nerve endigs causes pain in muscles, bones, or joints.

(3) Gas bubbles in the middle ear cause deafness, dizziness and headache, and vomiting.

(4) Formation of bubbles in the spinal cord causes paralysis of the lower half of the body.

(5) Their presence in the blood vessels of the brain causes loss of power to use or understand speech and various forms of paralysis: of a limb, of a part of the body, of one side of the body, or of the sense organs.

(6) Gas bubbles in the lung capillaries or in the right side of the heart are most serious, since they cause asphyxiation.

d. Treatment. The basic remendy for bends is recompression of the patient followed by adequate decompression. Decompression is based on the air treatment table (table IV). Treatment varies, depending on the nature and severity of symptoms. The following discussion is based on the use of a recompression chamber. It can be applied to regular decompression as well. Failure of this procedure to give complete relief probably indicates that tissue has been damaged. In such instances, the patient should be turned over to competent medical authorities.

TABLE IV.—*Air treatment table*

Initial recompression		Time at various stages (minutes)													
Feet	Pounds	140 ft. 62.3 lb.	130 ft. 57.85 lb.	120 ft. 53.4 lb.	110 ft. 48.95 lb.	100 ft. 44.5 lb.	90 ft. 40.05 lb.	80 ft. 35.6 lb.	70 ft. 31.15 lb.	60 ft. 26.7 lb.	50 ft. 22.25 lb.	40 ft. 17.8 lb.	30 ft. 13.35 lb.	20 ft. 8.9 lb.	10 ft. 4.45 lb.
100	44.5	....	....	....	....	....	....	....	....	....	....	14	42	52	68
150	66.75	....	....	....	....	....	....	....	....	22	30	35	42	52	68
200	89.0	....	....	....	....	....	7	22	24	26	30	35	42	52	68
250	111.25	....	....	....	13	18	19	22	24	26	30	35	42	52	68
300	133.5	4	14	16	16	18	19	22	24	26	30	35	42	52	68

(1) Recompress immediately until relief from symptoms is evident. Minimum recompression is to 100 feet (44.5 pounds). Add an excess of 15 pounds pressure and maintain it for 30 minutes. Decompress in accordance with air treatment table. If initial recompression was to pressure equivalent to 150 feet of water, use that line of figures. If 80 pounds pressure, the equivalent of about 180 feet, was applied, the 200-foot line of figures is used.

(2) Use of mixture of 40 percent oxygen and 60 percent of either air or helium has been found effective. Introduce mixture at 75 pounds pressure, and keep patient at that pressure until relief occurs or up to 2½ hours. Decompress as before.

(3) Note that treatment time is 4 hours at 150 feet and over 6 hours at 300 feet. This time can be materially reduced by use of 100 percent oxygen for 90 minutes. Patient puts on oxygen mask after he has been brought to 60-foot level in normal process of treatment. Treatment continues as usual until 90-minute period ends. Then return pressure slowly to atmospheric pressure. In an alternative method patient puts on oxygen mask, stops at 60-foot level in accordance with table, proceeds to 50-foot level and remains there for the balance of the 90-minute oxygen period, then is brought slowly to atmospheric pressure.

(4) If above methods are unsuccessful, increase pressure to 15 pounds above point of relief from symptoms, up to 105 pounds maximum. Maintain this pressure for 30 minutes, then reduce at rate of 1 pound per minute down to 140-foot level on air treatment table. Decompress as shown in table to 30-foot level. Make patient as comfortable as possible at that level, provide food, bedding, etc., and keep him there for 12 to 24 hours (overnight "soak") Then continue with usual decompression treatment.

(5) If diver is still not fully relieved, return to 75-pound pressure and maintain it as long as there is relief or up to 2 hours if diver is not relieved. Decompress at rate of 1 pound per minute to 140-foot level and proceed as in (4) above.

(6) If 40-60· oxygen-air or oxygen-helium mixture is available, use the same as in (5) above, except that diver remains at 75 pounds up to 2½ hours.

(7) When immediate symptoms before treatment are unconsciousness, paralysis, or asphyxiation, recompress immediately to minimum of 75 pounds and continue compression to 15 pounds above point of relief. Maintain that pressure for 30 minutes, then proceed as in (4), (5), or (6) above.

(8) Occasionally the symptoms recure sometime after treatment has been completed. In those cases, return patient to recompression chamber, treat as in (4) above.

(9) If a diver has suffered a "blow-up" but shows no symptoms of "bends," recompress to 75 pounds, maintain pressure for 30 minutes, and proceed as in (3) above.

(10) When a diver shows symptoms of illness after a "blow-up," recompress to 15 pounds above point of relief, and treat as in (3) above.

(11) A recompression chamber may not be available to treat a case of "blow-up." However treatment should be instituted whether or not there are symptoms of illness. Tenders set diver's valves and return him to bottom or a maximum depth of 165 feet. He remains there 30 minutes, then receives decompression treatment in accordance with air treatment table.

(12) The same method as in (11) above is used when symptoms do occur. However, if there is no relief at bottom pressure, the diver remains at bottom up to 2 hours. If there is relief, he remains at bottom as long as relief is

progressive. Thereafter, decompress at rate of 1 pound per minute to lowest comfortable level above 30 feet, and keep diver at that level as long as possible. Follow treatment table in bringing him to surface.

(13) If the diver is unconscious after the "blow-up" or if his condition is such that he cannot descend by himself, another diver accompanies him to the bottom, adjusting his valves for him.

41. AIR EMBOLISM. a. General. Air embolism is the entrance of air bubbles from the small blood vessels of the lungs into the left side of the heart and into the circulatory system when there is a sudden excess air pressure within the lungs as compared with outside air pressure. The average individual can stand only about ½-pound excess pressure per square inch. That safe margin is greatly exceeded during too rapid ascents in water, too rapid reduction of pressure in the recompression chamber, or when a diver holds his breath while pressure is being reduced.

b. Effects and treatment. Excess pressure of more than 3 pounds per square inch may rupture the capillaries in the lung, and may cause unconsciousness, paralysis, or death. It is treated by recompression.

42. ASPHYXIA. a. General. Asphyxia or suffffocation is due to—

(1) Deficiency of oxygen as a result of poor or inadequate air supply.

(2) Increase of carbon dioxide caused by improper ventilation of the helmet.

(3) Pressure on the diver's chest because of insufficient inflation of his dress, preventing him from breathing.

b. Symptoms. (1) Oxygen deficiency is rarely accompanied by symptoms; unconsciousness is likely to result without warning.

(2) Excess carbon dioxide manifests itself by causing headaches, sweating, and discomfort. In addition, the faceplate is likely to fog excessively.

(3) Tenders can detect a decrease in the volume of air bubbles coming to the surface, a sign that something is wrong. Immediate efforts should be made to communicate with the diver, to learn if he is all right.

(4) Generally, an asphyxiated diver will present this appearance: face blue or deep red, eyes bloodshot, muscles either limp or rigidly contracted; breathing may be weak, in occasional gasps, or entirely absent.

c. Treatment. When there is any suspicion of asphyxia and efforts to communicate with the diver are unsuccessful, start him toward the surface immediately.

(1) If the depth and duration of the dive are within the safe limits for surface decompression (table III), bring him to the surface at once at the rate of 25 feet per minute, place him in the recompression chamber, and give decompression treatment. Frequently, this will revive the diver. In more severe cases, administer artificial respiration. (See FM 21–10.)

(2) If the dive was outside the safe limits for surface decompression, raise the diver to the first decompression stop and again try to communicate with him. If he does not reply, bring him to the surface and treat as in (1) above.

(3) When a recompression chamber is not available, bring the diver to the surface as above and remove helmet and suit as quickly as possible. Administer oxygen if available and artificial respiration if necessary. After the diver has recovered, treat him for "bends."

43. BLEEDING. a. Bleeding or pains in ear. Ear bleeding and ear pains result from unequal pressure on either side of the ear drum when the diver is descending or ascending. Generally it occurs when the diver has a head cold or sore throat. Pressure may be sufficient to rupture the ear drum. The diver should report to the medical officer if severe pain or bleeding occurs.

b. Nose bleeds. Nose bleeds are usually caused by too strenuous efforts to clear the ears and are not serious in themselves. Severe nose bleeds may require medical attention.

c. Bleeding from lungs. Bleeding from the lungs is caused by air embolism or by "squeeze" when there is pressure on the chest because the dress is underinflated. Treat as for "squeeze," covered in paragraph 48.

44. "BLOW-UP." "Blow-up" results when the diver's dress is over-inflated and he becomes too buoyant. It can also occur if the tenders raise the diver too quickly or if a strong tide pulls the diver's lines and jerks him up. Air embolism or "bends" can result. Treat as explained in the discussion of compressed-air disease, paragraph (9) to (13).

45. DROWNING. Drowning during diving is a rare accident. It can be caused if the helmet is improperly fastened to the breastplate and comes loose during the dive. It can also occur if the faceplate is smashed or the dress torn. Administer artificial respiration in the recompression chamber.

46. EXHAUSTION. A man working under high pressure is liable to exhaustion much more quickly than under normal pressure. Keep the patient quiet and warm and get medical attention for him.

47. OXYGEN POISONING. Under pressure, oxygen irritates the lung and causes a condition similar to pneumonia. At 60 pounds pressure, approximately 135 feet, breathing pure oxygen for 45 minutes causes severe convulsions. A sense of excitement, a flushed face, and nausea are the first symptoms of poisoning. The patient requires immediate medical attention.

48. "SQUEEZE." "Squeeze" results from an accidental fall from shallow to deep water. It also occurs if the diver's dress tears, or if his air line ruptures and the nonreturn valve is leaking suddenly subjecting him to greatly increased pressure. Asphyxia, ruptured lung capillaries, or other serious internal injuries can result. Bring the diver to the surface at a maximum rate of 25 feet per minute, place him in the recompression chamber, and send for a doctor. In the meantime, raise the pressure slowly until he shows signs of relief. Give him oxygen to breathe at pressures of 30 pounds or less. Keep him quiet and warm.

49. MECHANICAL INJURIES. A diver may incur any sort of mechanical injury such as cuts, bruises, or broken bones. In such cases, bring him to the surface, apply the appropriate first aid (see FM 21–10), and secure medical attention.

SECTION X

UNDERWATER DEMOLITIONS

50. RECONNAISSANCE. Before demolition with explosives is attempted, a thorough investigation must be made to determine the type of work required. *Always determine the cargo of a vessel before undertaking any demolition of it,* and remove hazardous cargo, such as explosives and ammunition. Then determine what type demolition, that is, cutting, breaching, or flattening, is required, and the best method of accomplishing it.

51. CHOICE OF EXPLOSIVE FOR UNDERWATER CHARGE. To be satisfactory for underwater work an explosive must be insoluble and unaffected by water or enclosed in a waterproof container. TNT, tetrytol, composition C, and composition C–2 are satisfactory for such work. Commercial straight dynamite may be used if fired within 24 hours of submersion. Ammonium-nitrate explosives and nitrostarch should only be used in waterproof containers.

52. CALCULATION OF CHARGES. The formulas given below from FM 5–25 are satisfactory for underwater demolitions. However, maximum effectiveness is gained only with a crew experienced in such demolitions. Care must be taken in choice of method of demolition and explosive to accomplish the job. For details on normal calculation and placement of charges, see FM 5–25. In underwater demolitions, special care must be taken to prevent misfires caused by some part of the firing circuit becoming wet.

a. Steel-cutting charges. Use formula $P = 3/8\ A$, where P = number of pounds of explosives and A = cross-sectional area of member to be cut.

b. Timber-cutting charges. Use formula $P = \frac{D^2}{40}$, where P = number of pounds of explosives and D = least dimension of timber in inches.

c. Breaching charges. Use formula $P = \frac{R^3KC}{2}$, where P = number of pounds of explosives, R = breaching radius, K = material factor, and C = tamping factor (see FM 5–25).

d. Pressure charges (for bridges). Pressure charges are calculated by $P = 3H^2T$, where P = number of pounds of explosive, H = height in feet of stringer including flooring, and T = width in feet of stringer. Values of H and T are never taken as less than 1.

53. MAKING UP CHARGE. If possible, make up and prime the charge on deck to minimize underwater work. If it is too large to permit this, it is made into packages which can be readily handled and completely placed before the primer block of explosive is taken below.

a. When a sunken vessel is a menace to navigation, ammonium-nitrate bulk or cratering charges may be used as flattening charges principally to blow off the superstructure of vessels to be cleared.

b. Cutting charges are most satisfactory if made into flexible strips which can be curved to fit the contour of the object to be blown Two satisfactory methods of making up such charges are given below.

(1) Place explosive blocks on strip of canvas, cover with another strip, and sew or wire explosive in place. This flexible belt may be readily handled and easily placed.

(2) Run detonating cord through lengths of canvas hose and seal one end of hose. Fill hose with explosive (TNT may be broken up for this purpose) and seal other end. Charge is then primed and placed.

54. FIRING CIRCUIT. Underwater charges are best fired by an electrical firing system. The explosive may be fired by an electric cap or by denotating cord initiated by an electric cap. A series of charges may be fixed in an electric circuit, but single charges are more certain of detonation. For this reason it is sometimes preferable to make a number of dives to place single charges rather than to fire several simultaneously. In firing a series of charges simultaneously, detonating cord is preferable to direct electric wiring. A ring main should be used (see FM 5–25). The ends of the ring are brought together and fired by one primer, so the detonating wave will travel from both ends and insure detonation from either direction if the circuit be broken at any point.

55. WATERPROOFING CIRCUIT. Seal all nonelectric caps and detonating cord ends with cap-sealing compound. Asphalt, shellac, or soap may be used as substitute; do not use lubricating oil or grease or the cord will be damaged. Cover all electric wire splices with waterproof tape and coat with cap-sealing compound.

56. FIRING. *Never fire an explosive charge while divers are in the water.* Withdraw men from the water and observe all safety precautions in firing.

SECTON XI

UNDERWATER CUTTING AND WELDING

57. GENERAL. a. There is little difference in the theory and technique of underwater and surface cutting and welding. Even the equipment used is basically the same. Therefore, essential differences will be detailed only when standard practice and procedures must be altered to cover underwater operations. Otherwise adequate information is available in TM 1–430, 9–850, and 9–2852, Navy Diving Manual, 1943 edition, manufacturers' instructions and publications, and numerous textbooks

b. Divers should be thoroughly trained in practice and procedures. This is extremely important because a diver works under definite physical handicaps. The weight and bulk of his equipment hampers movement; adjustment of air supply requires constant attention; it is impossible to see effectively, and work must be guided by sense of feel, and lack of a suitable footing may compel him to use most of his strength to prevent himself from being swept away by currents. Even an experienced diver working under ideal conditions requires about five times as long to complete a job underwater as it would take him to do the same job above the surface.

58. PROCESSES. The processes used for underwater work include oxhydrogen cutting and electric arc-welding and cutting.

59. COMPARISON OF PROCESSES. a. Comparative cutting speeds on medium steel by gas and electric-arc underwater cutting torches are shown in figure 67. These curves represent the performance to be expected of an experienced operator under ideal diving conditions with good visibility, no water current, and a convenient position at a depth of 8 feet.

b. Curve *A* represents the cutting speed of the oxyhydrogen torch using a medium tip (one oxygen orifice No. 45 drill size and four fuel orifices No. 52 drill size). Better results are obtained when using a tip with six fuel orifices. Curve *B* represents the average cutting speeds of three different electric-arc cutting torches. Curve *C* gives the average cutting speeds of the same three electric-arc torches for brass, cast iron, and stainless steel. As can be seen by the curves, the arc torches are much more efficient on metal under 3/8 inch in thickness and are more easily used than the other torches.

60. UNDERWATER OXYHYDROGEN CUTTING. a. General. Hydrogen is used as the fuel for underwater gas cutting. Hydrogen is perfectly safe when subjected to extreme subsurface pressures; acetylene is not safe and therefore is never used for military underwater operations.

b. Torches. (1) The torches used in underwater cutting are almost identical with standard gas cutting torches. The tips, however, are so designed that the flame is surrounded with an envelope of air, which stabilizes the flame and keeps the water away from the spot being heated. A valve to regulate this supply of air is added to the usual controls on the torch (fig. 68). The distribution of air around the flame should be as uniform as possible.

(2) A distance guide is provided with the underwater torch to help the diver hold the torch at the correct distance from the work. A diver should,

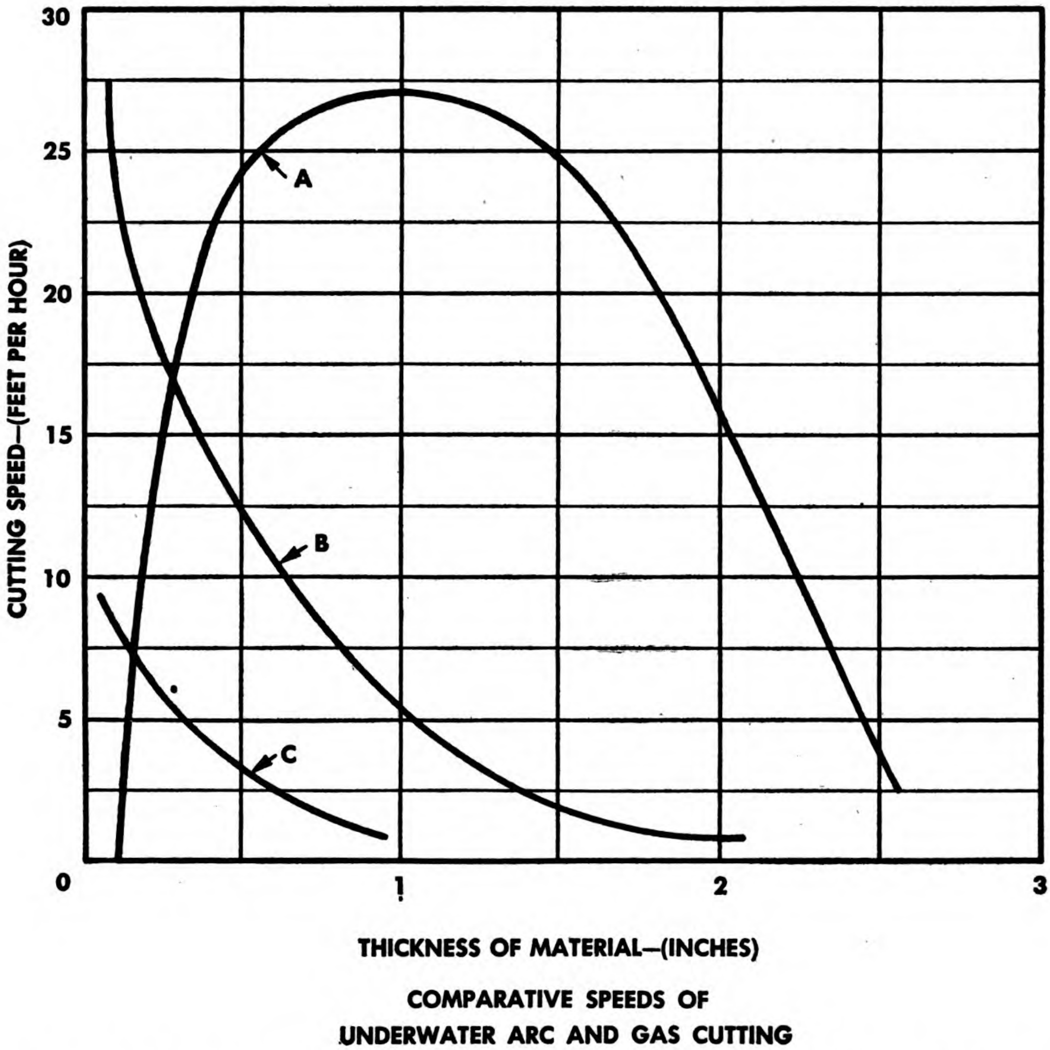


Figure 67. Comparative speeds of underwater gas and electric-arc cutting, presupposing ideal conditions and expert operator. (Curve A – cutting speed of gas torch; curve B – cutting speed of electric-arc torches; curve C – cutting speed of arc torches for brass, cast iron, and stainless steel.)

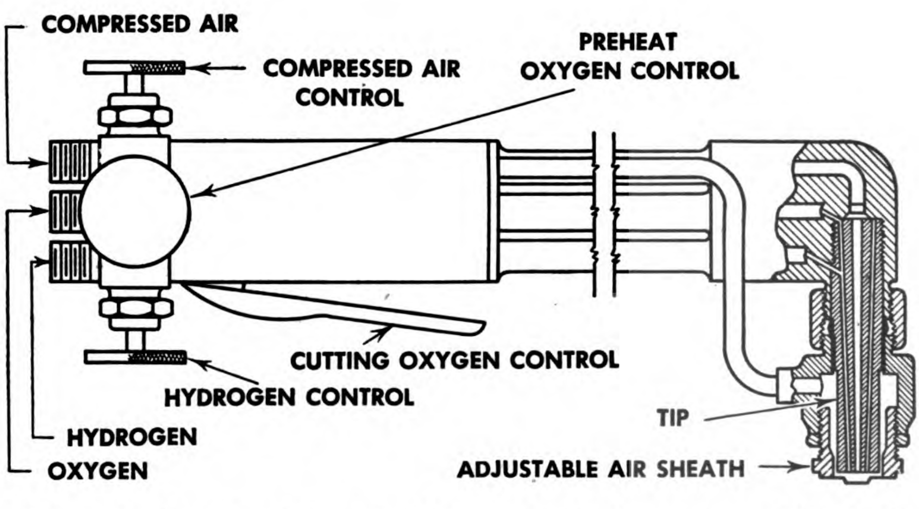


Figure 68. General scheme of underwater oxyhydrogen gas cutting torch.

however, learn the operate the torch without the distance guide, which frequently cannot be used.

61. GAS CUTTING PROCEDURE. a. General. Before making any connections, refer to publications listed in paragraph 57 for general considerations and precautions in the use of gas cutting apparatus.

b. Cleaning hose lines. In underwater welding, hoses are subjected to greater pressures than on the surface. The expansion of hose under pressure loosens up the soapstone, mixes it with the flow of gas, and eventually clogs torch strainers and valves, causing tips to melt and torch to fail. Soapstone must be removed as follows:

(1) Subject hose to pressure of 200 pounds to loosen soapstone.

(2) Blow out loose soapstone.

(3) Repeat above operations two or three times.

(4) Pass a bristle brush or other mechanical cleaner through hose.

c. Connecting oxyhydrogen apparatus. (1) Connect three oxygen cylinders and three hydrogen cylinders in a bank of six, using pigtails and manifold connections. Connect hydraulic flash arrestor as described in TM 1–430 or 9–2852.

(2) Connect reducing valve or regulator directly to hydrogen bank; connect hydrogen hose to regulator and torch.

(3) Connect air hose from supply of compressed air to torch.

(4) Set up heating unit near oxygen bank. Connect oxygen hose from oxygen bank to heating unit and from heating unit to torch. Heating unit consists of a small acetylene burner placed under oxygen receiving tank. This unit is not absolutely necessary but it produces better cuts, especially in cold weather, because it causes a more thorough mixture of gases.

(5) Make all connections gastight.

d. Operating torch. Refer to publications in paragraph 57 for general considerations and precautions.

(1) Set distance guide so face of tip is about 3/16 inch from metal being cut.

(2) Close all valves on torch.

(3) Determine distance work is below surface of water and set air, oxygen, and hydrogen supply gauges at pressures shown in table V for depth of work. Pressures thus tabulated are approximate; remember, increase of pressure is necessary to compensate for increase of water pressure over atmosphere, and regardless of pressure put on manifold, diver controls ultimate pressure at torch. Always inform diver when changing pressures at manifold.

TABLE V. *Working gas pressures for operating underwater cutting torch.*

Depth in feet	Water pressure in pounds	Length hose recommended in feet	Air in pounds	Gas pressure hydrogen in pounds	Oxygen in pounds
10	4.3	100	35	35	75
20	8.6	100	60	60	80
30	12.9	100	65	65	85
40	17.9	150	75	75	95
50	21.6	150	80	80	100
60	25.9	200	90	90	110
70	20.3	200	95	95	115
80	34.3	250	100	100	120
90	38.9	250	105	105	125
100	43.3	300	115	115	135
125	54.1	300	125	125	145
150	64.9	350	140	140	160
175	75.7	400	155	155	175
200	86.8	450	170	170	190
225	97.4	450	185	185	200

Note: This table is furnished so diver will have enough air and gases at torch for final adjustment and operation.

(4) Descend to work with torch and electric spark igniter; current for igniter is turned off during descent.

(5) Upon reaching work open air valve enough to form bubble about 3 inches long at torch tip. Hold torch vertically with tip horizontal. Close air valve and open preheat oxygen valve enough to form bubble about 2½ inches long.* Now reopen air and hydrogen valves to settings determined in (3) above.

(6) Turn on igniter current. Ingite torch by bringing together carbon contacts of igniter and holding torch over hole in handguard. Release contacts and spark will ignite torch.

(7) When torch is first lighted, observe it carefully.

(*a*) If properly lighted, a clear flame results and torch head and tip remains cool.

(*b*) Improper burning of gases causes a stream of small bubbles and a flame that is not clear; torch head and tip become hot.

(*c*) Always maintain more hydrogen than appears necessary for perfect combustion otherwise torch will backfire; in such case always turn off hydrogen first to prevent tip being burned out.

(*d*) If torch fails to light but produces short explosions each time igniter arcs, decrease oxygen.

(*e*) If torch remains lighted but will not cut, increase oxygen.

(*f*) If torch fails to cut cleanly all the way through metal, increase both hydrogen and oxygen.

(8) To be sure of proper cutting flame, attach test bar to torch. Hold torch close in front of helmet and adjust oxygen preheating valve and hydro-

* It may be difficult to adjust oxygen bubble to required length in freezing weather. Use heating unit (par. 61) or remove oxygen cylinders to some warm place such as an engine-room passage.

gen valve until test bar shows a white heat where flame is being applied, then pull high-pressure trigger. A hole will be blown through test bar if proper flame is available. Remove test bar and proceed as in ordinary gas cutting.

e. Cutting with gas torch. In practice, the use of the gas torch for underwater work is limited to the cutting of steel. Efficient results are not obtained in cutting cast iron, stainless steels, or nonferrous metals. Thin steel also presents considerable difficulty because of the lack of a metal mass to maintain the necessary preheat to support combustion.

(1) After adjustment of proper cutting flame, place torch on metal and hold it down firmly.

(2) When metal begins to redden and throw off sparks, pull back oxygen trigger slowly—*do not yank it wide open*—until metal is cut all the way through. Hold trigger in this position.

(3) In making a vertical cut, start at bottom and work up. The metal holds cutting heat better; burned particles will fall clear and not paddle the work. For any other cutting position, increase air supply to preserve the envelope of air surrounding flame.

(4) For quickly removing lines or cables fouled around propellers, use satisfactory surface flame; close adjustment as outlined above is unnecessary.

(5) Torch can also be used for surface cutting by removing distance guide and air sheath at tip.

f. After operation. Each time torch is used underwater, dry it carefully, disassemble head to remove all sediment, and thoroughly clean strainers and valves before sending it down again.

62. UNDERWATER ELECTRIC-ARC CUTTING. a. General As in the case of underwater gas cutting, standard electric-arc equipment has been adapted for underwater arc cutting. The electrodes used may be of carbon, graphite, or metal, and are tubular in order to introduce a jet of oxygen into the molten crater created by the arc, thus causing combustion of the metal along with the melting action. Either direct or alternating current may be used to produce the arc.

b. Electrodes. (1) The cross-section area of electrode is of little importance for efficient work although with a constant current a smaller cross-section will increase the speed of cutting because of the greater current density.

(2) Use 5/32-, 3/16-, or 1/4-inch waterproofed, covered mild steel electrodes (Navy grade FA) for cutting plate or castings; size depends on thickness of metal to be cut and current capacity of equipment. Speed of cutting and consumption of electrode are proportional to current used.

c. Waterproofing steel electrodes. Steel electrodes are waterproofed as follows:

(1) Cut 3/4 pound of ordinary transparent sheet celluloid into strips 1/8 to 1/4 inch wide.

(2) Dissolve these strips in 1 gallon of acetone, stirring with a metal rod.

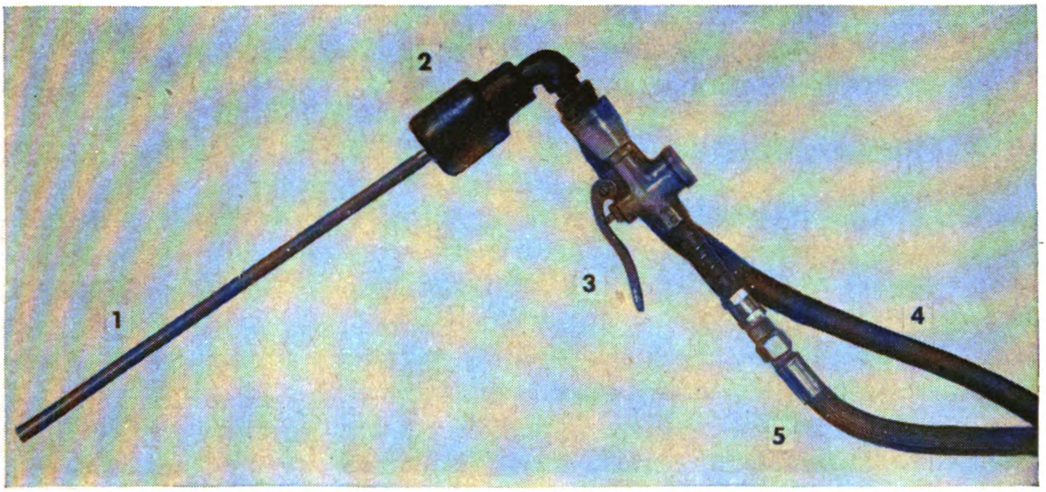
(3) Dip electrodes in solution but do not allow solution to cover grip end as this will cause poor contact between holder and electrode. Allow electrodes to dry. A piece of wood about 2 inches thick with 1/4-inch holes about 2 inches apart makes an excellent drying rack.

(4) Quantity of solution described above will coat about 250 pounds of 5/32-inch electrodes.

(5) Solution may be stored indefinitely in an airtight container; a 2-inch pipe, 14 inches long, capped at both ends serves satisfactorily.

(6) If ingredients for acetone-celluloid solution are not available, the electrodes may be dipped in a hot mixture of 60 percent beeswax and 40 percent paraffin wax. Cutting is more difficult with this solution.

d. Electric-arc torch. The underwater electric-arc torch is specially constructed of an electrode holder attached to an oxygen hose, a current cable, a ground cable, and a small valve operated by a lever which controls the amount of oxygen passing through the center of the electrode (fig. 69). The grip end of the electrode holder is made watertight with a rubber gasket. The electrode holder is then insulated as much as possible to prevent short circuits and rapid deterioration from contact with water. The electric cable and ground connections should be rubber- and friction-taped.



1. Electrode.
2. Electrode holder.
3. Oxygen regulating lever.
4. Electric power cable.
5. Oxygen hose.

Figure 69. Typical underwater arc cutting torch.

63. ARC-CUTTING PROCEDURE. See TM 9–2852 for general considerations and precautions.

a. Electric power. (1) A 50-kilowatt generator is used to supply current for underwater arc cutting. The most satisfactory cutting is done with a current of about 60 volts at 500 to 600 amperes.

(2) Two circuit breakers are provided in case diver suddenly places an excessive load on line. When a breaker kicks out, it should be quickly closed by the above-water attendant. While one breaker is being closed, the other handle should not be touched so if there is too great a load on the line at time of closing first breaker, the second breaker will trip.

b. Cleaning hose lines. In hot weather, coil excess hose and suspend it overboard in water to prevent undue heating which occurs when hose lays on deck.

c. Connecting electric-arc cutting equipment. (1) Connecting equipment for underwater electric-arc cutting is the same as connecting equipment for underwater welding. (See par. 61c and TM 9–2852.)

(2) Connect oxygen cylinder as described in paragraph 61. Set oxygen regulator at pressure of from 30 to 60 pounds per square inch, above water pressure at which diver is operating. Pressure chosen depends on the work.

(3) Start generator.

(4) Hold ground cable and torch tip overboard but widely separated. Throw in switches to test voltage of generator and to be sure of correct polarity. In salt water, this test should show a load of about 25 amperes.

(5) Straight polarity (electrode negative) is used for underwater arc cutting.

d. Operating arc torch. See TM 9–2852 for general considerations and precautions.

(1) Handle torch on deck with great care to avoid cracking electrode. A cracked electrode reduces supply of current and impairs efficient cutting.

(2) Diver should be provided with rubber or light canvas gloves before descending to overcome the slight electrical tingle sometimes felt underwater because of unavoidable electrical leakage.

(3) On descending, attach ground cable to plate or object to be cut. Obtain a good electrical connection; scrape off dirt or paint if necessary. A bolt inserted in a rivet hole or a *C*-clamp may be used.

(4) Turn on oxygen; signal for switching on current. If arc is struck before oxygen is turned on, electrode will melt thereby closing tip and preventing oxygen from flowing through.

(5) Start the arc as described in TM 9–2852.

64. CUTTING WITH ARC TORCH. a. Hold torch vertically with shield of electrode riding directly against material being cut. This requires constant pressure by diver. Any change from this position produces unsatisfactory results.

b. Oxygen oxidizes metal and blows it completely through plate as long as preheating arc and constant speed is maintained.

c. A red arc producing sparks indicates proper cutting. Bright green and yellow flashes indicate metal is not being cut.

d. Metal up to 1 inch thick can be cut by melting a series of connected holes through it.

e. Never burn down electrodes to less than 1½ inches long as heat will damage rubber cover of holder and make it difficult to replace the electrodes.

f. When through cutting, signal topside to switch off current.

g. Do not turn off oxygen valve until arc has been broken and electrode is clear of plate. A small amount of oxygen is allowed to escape through tip of torch to prevent water from backing into hose.

h. Each time torch is used underwater, dry it carefully, remove all dirt, and check thoroughly before sending it down again.

65. UNDERWATER ARC WELDING. a. General. The Army uses standard electric-arc welding equipment converted to underwater work by using insulated electrodes, (par. 62c), electrode holders, and cable designed for the electric underwater cutting torch.

b. Electric power. Current is supplied by a single-operator, 200- or 300-ampere d-c welding set, sending 35 volts at approximately 185 amperes across the arc. The 50-kilowatt generator used with underwater cutting torches may be used but must be modified for underwater welding operations. Higher voltage and amperage is used for welding underwater as shown in table VI. Care must be exercised because higher voltage and current often produce heavy undercutting (par. 68c (4)).

TABLE VI. *Comparison of approximate current values used for surface and underwater welding.*

Size of electrode	Surface		Underwater	
	Volts	Amperes	Volts	Amperes
5/32"	22-5	91-120	22-28	130-150
3/16"	24-28	120-150	28-35	150-175

c. Polarity. See TM 9–2852 for detailed discussion of polarity. Straight polarity is used for underwater welding. In salt water, reversed polarity causes rapid deterioration of any exposed metal parts of the electrode holder.

d. Electrodes. See TM 9–2852 and paragraphs 62b and 66.

e. Limitations. The material to be welded is more or less limited to medium steel, although emergency repairs can be made by attaching medium steel patches over holes in alloy and high carbon steel.

66. ARC-WELDING PROCEDURE. a. General. See TM 9–2852 for detailed procedure covering installation and operation of electric-welding machine and current selection. A single-blade switch is used in place of the regular switch provided with surface welding machine. Equipment should also be provided with circuit breakers (see par. 63).

b. Testing polarity. It is difficult to distinguish between straight and reserve polarity unless diver is experienced in underwater welding. If in doubt, make the following tests:

(1) Place reverse polarity electrode in holder and start welding. If electrode makes a pronounced hissing sound, excessive spattering occurs, and poor penetration results, polarity is *straight.*

(2) Place a 1/4- or 3/16-inch diameter carbon stick in holder and strike an arc. If an arc can be drawn to produce a gap from 1/2 to 1 inch without going out and end of carbon stick forms point similar to a sharpened pencil, polarity is *straight.* If carbon stick dubs off when striking arc and arc is difficult to maintain, polarity is *reverse.*

c. Use of goggles. (1) Use No. 8 welding lens in clear water. Muddy water requires the use of No. 6 or No. 4 lens.

(2) Goggles with one lens removed are used to protect eyes for a quick job. Diver must use one eye at a time but such goggles leave both hands free.

(3) When much work is to be done, attach welding lens to helmet in place of faceplate guard.

67. WELDING WITH ELECTRODE. See TM 9–2852.

68. UNDERWATER CUTTING WITH WELDING ELECTRODE. a. General. Divers must be trained in underwater cutting with electrode. If other equipment is available for underwater cutting, it should be used in preference to the welding electrode. At times, however, the electrode may be the only equipment available. Then, too, it is often used for cutting nonferrous metals.

b. Electric power. Much more current is used for electric cutting than

welding. See table VII of approximate current values. See paragraph 66b for correct polarity.

TABLE VII. *Approximate current values for cutting with electrodes on surface and underwater.*

Size	Surface		Underwater	
	Volts	Amperes	Volts	Amperes
5/32"	40–50	125–150	40–50	175–210
3/16"	50–60	160–200	50–60	200–250
1/4"	60–80	200–250	60–80	250–300

c. Procedure. See paragraph 66a, b, and c.

(1) Angle of electrode varies according to material being cut. For underwater work, it should be held 5 to 30° from the vertical into direction of cut.

(2) After starting arc, allow edge of plate to start melting; then oscillate electrode in vertical position. Be sure electrode goes completely through plate. Vertical oscillating motion of electrode also brushes molten metal from space being cut (kerf).

(3) Most common difficulty is not cutting completely through plate or casting. Before advancing electrode *be sure* it goes through and molten metal is falling clear of cut. Make kerf wide enough to move electrode up- and-down and sideways without difficulty. Kerf should be 3/8-inch wide for best results.

(4) Using 300 emperes and 50 volts, steel plate can be cut underwater rapidly. Punch a connected series of holes through plate with electrode. Cuts will be about ½ inch wide and can be made at rate of 1 foot in 2 minutes in ½-inch plate. Copper composition and cast iron are also cut in this way.

(5) In all cases of underwater arc cutting, find position that permits best vision without interference from bubbles and cuttings. Take advantage of underwater current by working in a position that will allow it to carry away bubbles and cuttings.

INDEX

INDEX